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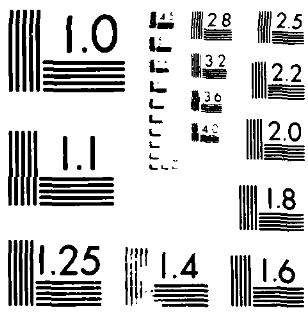

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Department of the Army
St. Paul District
Corps of Engineers

Analysis of Existing Hydrologic Models, Red River of the North Drainage Basin North Dakota and Minnesota

CH2M HILL

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Increased flood damages in the Red River of the North prompted investigations into the probable causes of increased flood severity. Increased flooding may be related to the recently common practice of installing agricultural drain-tiles and ditches. This study evaluates thirteen hydrologic models to determine which are best suited to the analysis of the causes of increased flooding. Three models, the Hydrocomp Simulation Program Fortran version (HSPF), the Runoff and Routing model (RROUT) and the Minnesota Model for Depressional Storage (MMDW) hold the greatest promise.

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CHAPTER 1
INTRODUCTION AND STUDY APPROACH

During the spring thaws of 1978 and 1979, the Red River of the North experienced widespread flooding, resulting in millions of dollars of damage and loss of lives. The severity of the flooding has spurred interest in the possible causative factors. Some have suggested that the drainage of wetlands for agricultural use may be the one factor most directly responsible for the apparent increase in flooding. The drainage of lands in the major tributary areas of the Red River of the North began in the early 1900's. Since that time, it is estimated that upwards of 4.5 million acres of land have been drained in order to enable normal agricultural practices.

In recent years, the area has also experienced an increase in the frequency of the higher flood stages along the main-stem of the Red River of the North. Is this increase in the flooding due either wholly or in part to the drainage of the lands? What measures can be instituted to minimize the damages when excessive runoff and flooding do occur? The Soiris-Red-Rainy Regional Committee has proposed that special studies be undertaken to address these perplexing questions. The St. Paul District of the U.S. Army Corps of Engineers has taken the initial step toward such a study by commissioning a review of existing hydrologic and hydraulic models in order to identify those most suitable to the analysis of the questions posed above. The results of this model review are reported herein.

The analysis of existing hydrologic models potentially suited to the study of the causes of increased flooding in the Red River of the North drainage basin began with a familiarization with the study area. The area of concern encompasses the entire United States portion of the Red River of the North basin, i.e., a large area in North Dakota and in Minnesota outlined in Figure 1. However, it was determined that the model review would concentrate on model application to two representative subwatersheds, the Rush River in North Dakota and Marsh Creek in Minnesota.

Analysis of hydrologic models suited to flooding studies in the Rush River and Marsh Creek was performed in three phases:

1. Preliminary Model Selection and Evaluation
2. Detailed Model Investigations
3. Data Base Considerations

The preliminary model selection and evaluation, discussed in Chapter 2, identified the criteria applicable to the evaluation of a model's suitability to analysis of Red River of

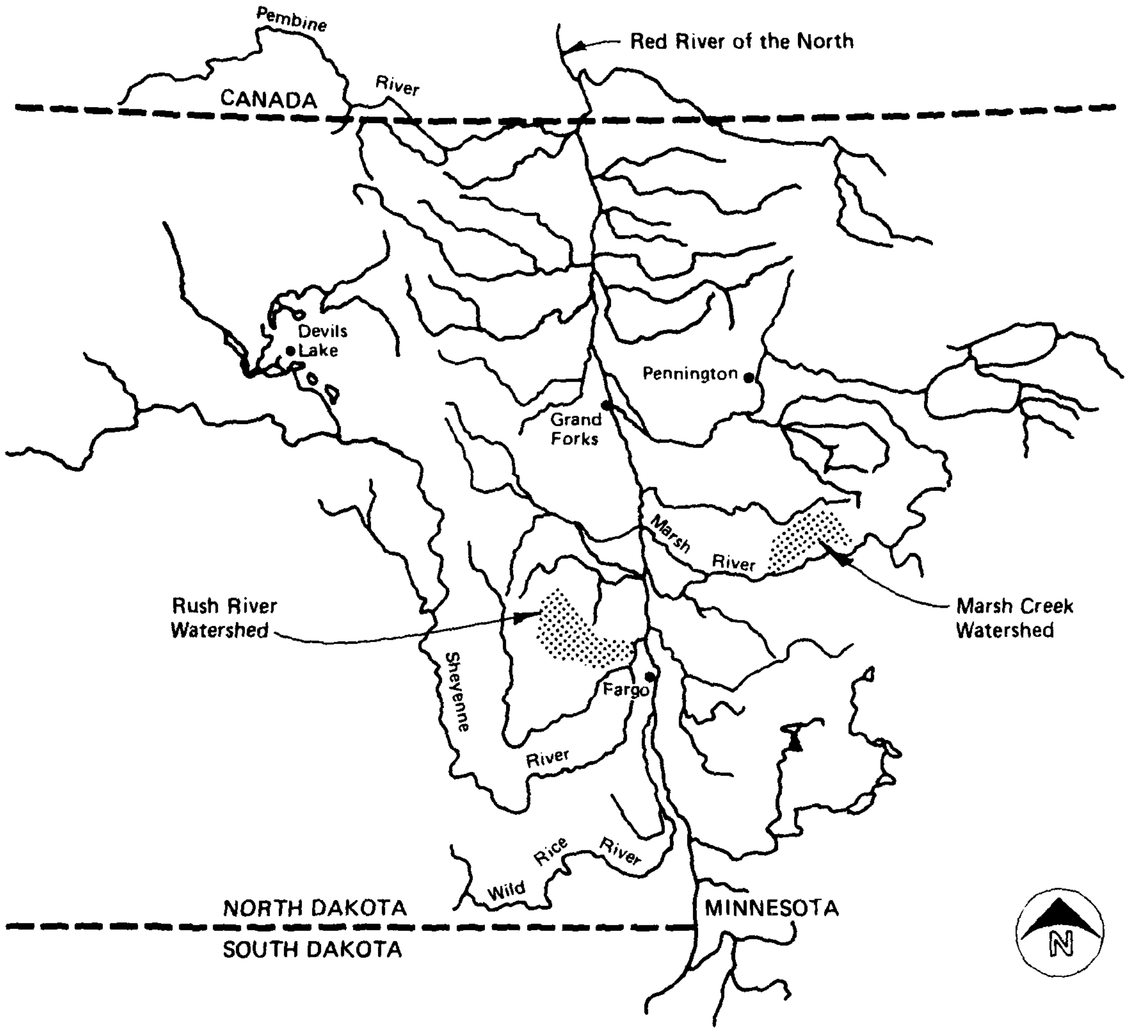

FIGURE 1
RED RIVER BASIN

the North type hydrology and evaluated ten currently available models in terms of these criteria. Three of the models evaluated, the Hydrologic Simulation Program Fortran Version (HSPF), the Runoff and Routing Model (RROUT), and the Minnesota Model for Depressional Watersheds (MMDW), compared well with the criteria and were identified for more detailed analysis.

The detailed investigation of these models is discussed in Chapter 3. Each of the models is evaluated in terms of its ability to represent Red River of the North type hydrology, its adaptability to small basin analysis and its data requirements. Comparison of these models concluded that the RROUT modeling approach is most advantageous for flooding analysis in the study area. The RROUT modeling approach incorporates the advantages of well tested, continuous hydrologic simulation through use of the Stanford Watershed Model (or one of its derivatives) to calculate land surface runoff. It significantly reduces costs by selecting only critical portions of the continuous hydrograph for detailed hydraulic routing. The approach was developed with inherent capabilities to predict flood frequency and facilitate flood analyses.

The data needs for the RROUT modeling approach are discussed in detail in Chapter 4. The sources and methods of collecting the data required for hydrologic modeling of the Rush River using RROUT are discussed in detail. Meteorologic data needs can be met primarily from data on file with the National Climatic Data Center. Topographic and physiographic data are available from a variety of sources and need be supplemented primarily with informal windshield surveys. Hydraulic data and hydrologic calibration data must be field collected for successful analysis of Rush River hydrology.

Conclusions of the analysis of existing hydrologic models are synopsized in Chapter 5.

CHAPTER 2
PRELIMINARY MODEL SELECTION AND EVALUATION

FAMILIARIZATION WITH THE STUDY AREA

On October 22 and 23, 1979, the study team visited the Red River of the North to become familiar with the study area and nature of the problems through reconnaissance and interviews with knowledgeable parties from the State and government agencies. On October 22, Wesley Blood and Randy Videkovich of CH2M HILL, and Gordon Heitzman of the Corps of Engineers, toured the Marsh Creek drainage basin with Peter Colin, Minnesota State Surface Water Hydrologist, Minnesota Department of Natural Resources. On October 23, Wesley Blood, Randy Videkovich and Gordon Heitzman toured the Rush River drainage basin in North Dakota with David Sprynczynatyk and Dale Miller of the North Dakota State Water Commission. On the afternoon of the 23rd, a meeting was held with Dr. Bharat M. Parekh to discuss the Devils Lake, North Dakota, modeling work which he is conducting at North Dakota State University.

The tours and discussions provided an infusion of information into the model evaluation process. The following points summarize this information:

- Major floods are the result of snowmelt and/or rain with snowmelt. Therefore, the model selected should be able to simulate the accumulation and melt of the snowpack.

- The primary problem of interest is the flooding associated with the major runoff events. The model does not need to address the problems of water quality, sedimentation or low flow.

- Due to the nature of the topography, the procedure the model uses for computing rainfall excess and the ability to handle depressional storage and ponding is crucial to the successful application of the model.

- The existing and/or proposed drainage ditches can be treated as a part of the stream channel network for the purpose of routing flows.

- It will not be necessary to directly simulate the effects of the subsurface drainage systems in the Red River of the North drainage basin.

- In North Dakota, drainage projects of 80 acres or smaller do not need to go through the permit process. As a result of this policy, it is not known how many total acres have been drained.

- In Minnesota, drainage projects that alter the course, flow or cross section of any designated public waters are regulated by the State. All other drainage activities (such as drainage of farmlands) are regulated by the county codes. The amount of on-farm drained acreage is unknown.

- The Devils Lake Watershed model is an application of the HYDROCOMP HSPX proprietary program to the Devils Lake drainage area. In order to simulate the unique characteristics of the drainage area, modifications to the data input stream and repetitive runs have been made. Changes to the program's computational algorithms have not been made. North Dakota State leases the program on an annual basis from HYDROCOMP, Inc. Results of applying this simulation methodology to the Devils Lake area have been quite good.

- The model selected for application should be able to simulate the approximate preproject drainage conditions in order that an evaluation of the impact of drainage projects on mainstem flooding can be made.

- The effectiveness of alternatives for flood mitigation will need to be evaluated through the use of the selected model.

CRITERIA FOR MODEL EVALUATION

Based upon these observations, discussions with knowledgeable individuals, and CH2M HILL's perception of the problems that need to be addressed, several criteria were compiled for the Phase I model evaluation. The selected model should be:

1. capable of simulating the runoff due to snowmelt and rain with snowmelt;

2. capable of simulating the wetland and depression storage effects;

3. capable of simulating the effects of surface drainage projects;

4. capable of accurately routing flows in the tributaries and the mainstem of the Red River of the North under dynamic flow conditions;

5. composed of model algorithms based upon proven hydrologic and hydraulic principles and well tested in terms of previous applications;

6. available and have data base requirements which are not excessive;

7. able to simulate a continuous moisture balance so that assumptions do not have to be made regarding antecedent soil moisture prior to running a hypothetical or design storm;

8. capable of simulating runoff from both small and large drainage areas; and

9. capable of producing runoff events and analyzing alternatives at a reasonable cost.

MODEL SYNOPSIS AND COMPARISON

The thirty-six models listed in Appendix B were screened and thirteen were selected for evaluation. The screening was a cooperative effort on the part of those staff members of CH2M HILL with significant modeling experience, augmented by telephone interviews with key personnel from various State and Federal agencies, such as the Hydrologic Engineering Center in Davis, California; the Hydrologic Research Laboratory of the National Weather Service in Silver Springs, Maryland; and the U.S. Department of Agriculture Hydrographic Laboratory in Beltsville, Maryland.

The key considerations used in the screening process were:

- Is the model proven to be operational and has it been applied successfully?
- Is the model designed for a special area or for a special type of application such as urban areas only?
- Would it be impractical to attempt an application of the model to the Red River of the North basin?
- Is the model of a generic group where there is not enough difference to consider it by itself?

From the screening process, the following models were selected:

1. Devils Lake Basin Model (DLBM);

2. Flood Hydrograph Package (HEC-1);

3. Hydrologic Simulation Program-Fortran Version (HSPF);

4. Hydrologic Modeling, Problem-Oriented Programming Language (HYMO);

5. Massachusetts Institute of Technology Catchment Model (MITCAT);

6. Runoff and Routing Model (RROUT);

7. Streamflow Synthesis and Reservoir Regulation Model (SSARR);

8. Storage, Treatment, Overflow Runoff Model (STORM);

9. Project Formulation Hydrology (TR-20);

10. USDA Hydrographic Laboratory Model (USDAHL-77);

11. USGS Rainfall Runoff Model (USGSRR);

12. Illinois Urban/Rural Drainage Area Simulator (ILLUDAS); and

13. Minnesota Model for Depressional Watersheds (MMDW)

The selection of these models for further evaluation represents a comprehensive assortment of models that are currently being used to address runoff and flooding problems throughout the country. The individual models were, for the most part, designed to be general and universally applicable.

In order to synopsize the important aspects of the models and provide information for comparative purposes, an evaluation form was prepared. A form was completed for each of the models listed above. The questions used and the completed forms are contained in Appendix C.

A matrix summarizing the pertinent information is presented in Table 1. In those few instances where a question mark was used, it was due to the inability to obtain certain information. The information lacking was not considered critical to the evaluation process.

FINDINGS AND RECOMMENDATIONS

Findings

The investigations conducted indicate that there are few existing models that were conceptually formulated to handle wetland and depressional storage. This complicates the process of finding a model that is ideally suited for the hydrologic and hydraulic conditions that exist within the Red River of the North drainage basin. Of all the models

Model Name	Continuous or Event	Program Language	Generally Available or Proprietary	Simulate Snowmelt	Simulate Depressional Wetland Storage	Simulate Surface Drainage Projects	Simulate Sub-surface Drainage Projects	Open Channel Flow Routing	Spatial Varability of Precipitation	Calculates Water Balance	Reproduce Historic Flows	Compatible with Major Computer Systems	Cost Comparison with Other Models
DLBM	Cont.	PL-I	Prop.	Yes	Implicitly	Yes	Implicitly	Yes	Yes	Yes	Yes	IBM only	High Range
HEC-1	Event	Fortran IV	Avail.	Yes	No	No	No	Yes	Yes	No	Yes	Yes	Medium Range
HSPF	Cont.	Fortran IV	Avail.	Yes	Implicitly	Yes	Implicitly	Yes	Yes	Yes	Yes	Yes	High Range
HYMO	Event	Fortran IV	Avail.	No	Implicitly	Implicitly	No	Yes	Yes	No	?	Yes	Low Range
ILLUDAS	Event	Fortran IV	Avail.	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Medium Range
MITCAT	Cont. or Event	Fortran IV	Prop.	No	Implicitly	Yes	Implicitly	Yes	Yes	?	Yes	Yes	Medium Range
MMDW	Cont.	Fortran IV	Avail.	Yes	Yes	Yes	Yes	Yes	?	Yes	Yes (limited)	Yes	Very High
RROUT	Cont. or Event	Fortran IV	Avail.	Yes	Implicitly	Yes	Implicitly	Yes	Yes	Yes	Yes	Yes	Medium Range
SSARR	Cont.	Fortran IV	Avail.	Yes	Implicitly	Implicitly	No	Yes	Yes	No	?	IBM CDC	Medium Range
STORM	Cont.	Fortran IV	Avail.	Yes	Implicitly	No	No	No	Yes	No	No	Yes	Medium Range
TR-20	Event	Fortran II	Avail.	No	Implicitly	Yes	No	Yes	Yes	No	Yes (limited)	Yes	Low Range
USDAHL	Cont.	Fortran IV	Avail.	Implicitly	Implicitly	No	No	No	No	No	Yes (limited)	Yes	Low Range
USGSRR	Cont.	Fortran IV	Avail.	No	Implicitly	Yes	Implicitly	Yes	Yes	Yes	Yes	Yes	Medium Range

TABLE 1

MODEL CAPABILITY COMPARISON MATRIX

that were considered, only the Minnesota Model for Depressional Watersheds is structured to simulate depressional and wetland storage directly. Several of the other models can treat depressional storage indirectly by means of an upper zone storage function. These include the Devils Lake Basin Model, the Fortran version of the Hydrologic Simulation Program (HSPF), and the Stanford Watershed Model utilized by the Runoff and Routing model (RROUT). In these models, an upper zone storage parameter is determined through the calibration process.

Significant work and model development for depressional topography has been conducted at Iowa State University by Haan, Campbell, and Johnson. The development of the MMDW at the University of Minnesota has built upon this earlier work. There do not appear to be any features of the Iowa State model that are not contained in the MMDW. For this reason, the Iowa State model was not included in the evaluations.

The Stanford Watershed Model (SWM) is the forerunner of a large number of existing hydrologic models. These include the Kentucky Watershed Model, the Georgia Tech Watershed Model, the Texas Watershed Model, the National Weather Service version, the Ohio University version, the Devils Lake Basin Model (DLBM) and the Fortran version of the Hydrological Simulation Program (HSPF). The HSPF, DLBM and SWM (as utilized in RROUT) were considered in the evaluations. The other models do not offer any significant advantages over those considered, so they were not included in the evaluations.

Recommendations

Accurate simulations of flood flows in the Red River of the North drainage basin depend upon many factors or processes. The more critical factors include snowmelt, computation of excess rainfall and the overland and channel flow routing. Based on consideration of these factors, the following are recommended:

- A model that simulates snowmelt on the basis of conservation of heat (energy) should be utilized.
- A model that either directly or indirectly simulates the effects of depressional storage and ponded water should be utilized.
- A model that performs a continuous soil moisture accounting should be utilized.
- A model that uses, at a minimum, a semidynamic streamflow routing procedure should be utilized.

- The adequacy of the selected models for routing flows in the Red River of the North mainstem should be evaluated further. The possibility of using a watershed model in conjunction with a superior open channel flow routing procedure, such as the Dynamic Wave Operational Model (DWOPER), should be considered. This model is part of the National Weather Service River Forecasting System.

Of the models that were evaluated, those that appear to come the closest to fulfilling the Red River of the North modeling requirements, are:

1. The Hydrological Simulation Program Fortran version (HSPF). This is the same as the Devils Lake Basin Model but is not proprietary;

2. The Runoff and Routing model (RROUT) that utilizes the Stanford Watershed Model land phase processes; and

3. The Minnesota Model for Depressional Watersheds (MMDW).

CHAPTER 3
DETAILED MODEL INVESTIGATIONS

DETAILED MODEL DESCRIPTIONS

Hydrological Simulation Program--Fortran (HSPF)

As briefly discussed in Chapter 2, HSPF is a new program release from the Environmental Protection Agency (EPA). The program was developed for EPA by HYDROCOMP, Inc., located in Mountain View, California. HSPF is a much improved and greatly expanded version of the Stanford Watershed Model that was developed in the mid-sixties at Stanford University.

Computer Compatibility

The HSPF computer source code is rather extensive. It consists of some 65,000 Fortran statements and 500 subprograms. However, the program is structured in such a manner that only those subprograms required for the particular application run are loaded in the computer. As presently structured, the program requires a maximum of 250K bytes of core storage. The program is written in standard ANSI Fortran IV. It utilizes the half-word integer feature available on certain systems, such as the IBM 360 and 370 series. This permits two parameters that can be represented as integers to be packed into one normal or floating point word length. Programming was done in this manner in order to reduce the core storage requirements. Due to the extensive data base requirements and data series manipulations conducted by the program, a direct access disk operating system is required. The program load modules and data series need to reside on a disk pack that can be readily mounted on a disk drive for required computer runs.

The University of Minnesota Computer Center utilizes a CYBERNET 74. This computer, manufactured by Control Data Corporation, is an excellent computer for scientific applications that usually entail a lot of "number crunching." HSPF source code is generally compatible with the CYBERNET 74, with one notable exception. The Fortran IV compiler of the CYBERNET 74 does not support the half-word integer feature. A significant modification effort would be required in order to bring HSPF up on the CYBERNET 74. Rob Johanson of HYDROCOMP estimates a 3 to 4 man-month effort at a cost of $15,000 to $20,000 (computer time included) in order to modify HSPF for those systems that do not have the half-word integer feature available.

Both the Boeing Computer System (BCS) and the Central Data Processing Center of North Dakota utilize the IBM 370/178 computer system. Both computer systems support the half-word

integer and mountable disk requirements of the HSPF program. As of this writing, the HSPF program is being loaded on the BCS computer facility located in McLean, Virginia. It should load without significant difficulty on any large IBM computer system.

Theory and Methodology

In general, the HSPF methodology was developed to simulate the processes of the hydrologic cycle. The hydrograph of streamflow is simulated as the end product of the variable time and areal distributions of precipitation (rain and/or snow), evapotranspiration, infiltration and soil moisture conditions, and physical watershed characteristics. Simulation is termed continuous because the processes of the hydrologic cycle are continuous in nature, and they are treated as such in the HSPF methodology. Continuous time series of precipitation and climatological data are provided to the program, and a continuous hydrograph of streamflow is computed at as many locations within the watershed as desired. In the process, soil moisture is accounted for on a continuous basis as well as ground water, and depressional and interception storages.

Overland Flow and Overland Flow Routing. This component of runoff, as well as the interflow and ground water components, are computed in what is referred to as the "LANDS" phase of HSPF. The methodology utilized is one of the strong features of the program and is essentially that used by the Stanford Watershed Model. The overland flow is determined as either excess rainfall, snowmelt, and/or rain combined with snowmelt. The actual amount of overland flow is determined at discrete time steps (1 minute to 24 hours as specified by the user) as a function of the variable depressional storage, infiltration capacity, soil moisture, and, if applicable, the condition of the snowpack.

Infiltration is the most significant single process that diverts precipitation from direct runoff and immediate streamflow. Therefore, this becomes the key process in determining the overland flow component of runoff. Infiltration capacity is defined as the maximum rate at which a soil will accept infiltration. It is a function of the fixed characteristics of the watershed, such as soil type and permeability, land slopes and vegetal cover, and of variable characteristics, primarily the soil moisture content. The basic HSPF algorithms for infiltration are built around the equations developed by Phillips:

$$F = st^{1/2} + at \qquad (1)$$

$$f = \frac{st^{-1/2}}{2} + a \qquad (2)$$

where

F = the cumulative infiltration
f = the infiltration rate
t = time and
s,a = soil property constants

Assuming "a" to be a very small value, we obtain:

$$fF = \frac{s^2}{2} \qquad (3)$$

Since $s^2/2$ is a constant, the above equation relates the infiltration rate to the cumulative or infiltrated volume. Homogeneous soil is assumed, but a decrease in permeability with depth is more common. Therefore, the above equation was modified as follows:

$$fF^b = \text{constant} \qquad (4)$$

where

b = a constant

Another concept used in the HSPF infiltration algorithms is that of a varying infiltration capacity for a fixed "homogeneous" watershed segment. Even in relatively homogeneous watershed segments, it has been shown that infiltration capacity varies from point to point. To simulate this phenomenon, HSPF assumes that infiltration capacity fits a uniform distribution. The actual infiltration capacity during a discrete time step, as defined by the above relationships, depends upon two parameters, the values of which are determined through a calibration procedure. During the time step, the amount of water available for overland flow is determined by the infiltration algorithms acting upon the available water supplied by precipitation and/or snowmelt.

In HSPF, overland flow is treated as a turbulent flow process. Since continuous surface detention storage is computed, the volume of surface detention was chosen as the parameter to be related to overland flow discharge. HSPF solves the continuity equation:

$$D_2 = D_1 + \Delta D - q\,\Delta t \qquad (5)$$

where

D_2 = surface detention at the end of the current time interval,
D_1 = surface detention at the end of the previous time interval,
ΔD = the increment added to surface detention in current time interval
Δt = the time interval, and
q = the overland flow rate into the stream channel during the current time interval.

The Chezy-Manning equation is also used to give a functional relationship

$$q = \phi(n, S, L, d, d_e) \qquad (6)$$

where

n = Manning's roughness coefficient,
S = the slope of the flow plane,
L = the length of the flow plane,
d = the depth of surface detention at any instant, and
d_e = the depth of surface detention at equilibrium conditions

The system of equations derived from the continuity and Chezy-Manning relationships are solved numerically to obtain the actual discharge from overland flow.

Based upon many previous applications, the procedure for determining overland flow produces very good results.

Snowpack and Snowmelt. The storage of precipitation in the snowpack, followed by the release of water as snowmelt, contributes to the major flooding events in the Red River of the North drainage basins. Hence, the model's ability to predict snowmelt on the bases of snowpack and meteorological conditions is of paramount importance. HSPF snow accumulation and snowmelt algorithms utilize an energy balance approach. The algorithms are based upon work by the U.S. Army Corps of Engineers (1956), Anderson and Crawford (1964), and Anderson (1968). They consist of a combination of physical and empirical relationships. Empirical relationships are used only when the physical relationships are not well known.

The snow algorithms use meteorologic data to determine whether precipitation is falling as rain or snow, to simulate an energy balance for the snowpack, and to determine the net effect of various energy (heat) exchanges on the snowpack. Air temperature is the index used to determine when snow is falling. If snow falls in significant amounts, snowpack accumulation and snowmelt computations take place. Sources of heat which influence the melting of the snowpack and are simulated in HSPF are:

1. net radiation, both incoming shortwave and longwave from back radiation

2. convection of sensible heat from the air movement

3. latent heat transferred by condensation of moist air on the snowpack

4. sensible heat from the falling rain and latent heat from rain freezing on the snowpack, and

5. conduction of heat from the underlying ground to the snowpack.

Other heat exchanges, such as the latent heat from evaporation, are considered to be less significant and are not simulated. For uniformity and accounting purposes, all heat exchanges are calculated in terms of the water equivalent which would become melt. The relationship of 202.4 calories/cm^2 required to melt 1-inch water equivalent of snow at 32°F is utilized. All sources of heat are considered to be positive (incoming to the pack) or zero, with the exception of the longwave radiation emitted by the snowpack.

All incoming heat from the atmosphere is used to warm the snowpack. Any excess heat above that required to warm the snowpack to 32°F is used to melt the pack. Likewise, net loss of heat is used to cool the pack, producing a negative heat storage. The incoming heat from the ground, when it occurs, is used to melt the snowpack from the bottom independent of the atmospheric heat sources.

Provisions are contained within the snow algorithms for the melting and subsequent refreezing of water within the snowpack, determining the density of the pack, and for defining the aerial coverage of the snowpack.

Five meteorologic time series are required for snowmelt simulation for each type of land segment simulated. They are:

1. Precipitation (usually hourly)
2. Air temperature (usually daily max/min)
3. Solar radiation (daily)
4. Dewpoint (usually daily average)
5. Wind movement (miles per day)

If a reasonably representative series of these meteorologic parameters can be provided, the HSPF snow algorithms produce very good results. Problems are encountered when temperature inversions exist and when the snowpack and meteorological conditions combine is such a manner that excessive liquid water is contained within the snowpack prior to a major snowmelt event.

Channel and Reservoir Routing. HSPF uses a routing technique which is a combination of "storage routing" and "kinematic wave" methods. Within certain boundary constraints, the solution procedure is accomplished explicitly during each time step. Two basic assumptions are made as follows:

1. There is a fixed relationship between depth (at the deepest point in the channel reach), surface area, and volume.

2. For any outflow from the reach that is a function of volume, the functional relationship remains constant with time.

These assumptions preclude the simulation of the class of flows where flow reverses in direction, and also those cases where the downstream reach would influence flow in the upstream reach in a time-dependent way.

One of the main advantages of the approach used in HSPF is that a channel reach can have any geometric shape (circular, trapezoidal, natural, etc.), or the reach can be specified as a reservoir. The solution algorithms proceed in the same manner for either case.

The basic component of the computational procedure is what is termed a "reach table." The information contained in the table is computed external to the program, and a table must be specified for each reach included in the network. The user specifies the properties of each reach, whether a channel or a reservoir, as a function of the depth. Volume, surface area, and discharge must be specified. In addition, other diversions and/or reservoir releases can be specified either as a function of time or of volume. An example of a reach table for a channel reach is shown below:

Depth (Feet)	Surface Area (Acres)	Volume (Ac-ft)	Discharge (cfs)
0	0	0.0	0
2	1	0.5	5
4	2	3.0	10
8	4	5.0	30
10	9	10.0	100

The number of rows used depends upon the complexity of the cross section and the resolution that is desired. This procedure for channel routing provides the user with a great amount of flexibility.

One disadvantage of this simplified approach is its inherent inadequacy for routing flows in wide rivers with flat slopes (such as the mainstem of the Red River of the North). To accomplish this type of routing, HSPF should be used to input flows from the tributary areas to a more adequate routing model such as the National Weather Service Dynamic Wave Operational Model (DWOPER).

Data Requirements for Model Calibration. The process of applying HSPF, as with other models, requires a fitting or calibration of HSPF parameters to the watershed. Some parameters are measured directly from topographic maps or are readily determined by conventional hydrologic procedures. Other key parameters are obtained through experience and by making repetitive computer runs and adjusting parameters between runs so that simulated runoff matches recorded runoff as closely as possible.

For calibrating HSPF, the following time series should be available:

- Hourly precipitation
- Daily streamflow measurements
- Daily or semimonthly potential evaporation
- Daily maximum/minimum temperatures
- Daily wind movement
- Daily dewpoint
- Daily solar radiation

Ideally, the time series would cover a range of years or seasons which include a wet, dry, and normal set of conditions. In addition, information on land use and the history of snowpack (depth and extent) as a function of time are important. Included in land use data are soils maps, vegetative cover, wetland storage areas, depressional storage areas, and the percent of area that is impervious and is hydraulically connected to the drainage system.

The above-mentioned data are required by the "LANDS" phase of the hydrological simulation. In order to adequately simulate streamflow, information must be obtained to describe the natural and manmade drainage network. Channel cross sections may be obtained by field measurement or digitizing using appropriate aerial photography. Estimates are required of Manning's "n" (roughness coefficient) for the stream/drainage channel as well as the flood plains. In addition, the geometry of bridges and culverts must be obtained. All other information required to describe the drainage network can be measured from topographic maps.

Sensitivity Analysis

Successful simulation of watershed runoff is dependent upon many factors, some of which play a more important role than others. This section will identify those factors and model parameters that are significant and show some sensitivity relationships.

Of primary importance in successful simulation of watershed runoff is the precipitation series. Simulation results will be meaningless if a "representative" precipitation record (or records) is/are not available. It is not essential, that precipitation be measured within the watershed under study. "Representative" precipitation outside of the watershed can be transferred in for the purpose of producing long-term simulations. "Representative" means that the precipitation is produced by the same basic family of storms (convective, frontal, hurricane, etc.). Further, some estimate of the ratio of the average annual precipitation over the study watershed to that at the recording gauge is necessary.

The results of snowmelt simulation are sensitive to the time series of solar radiation, wind speed, maximum-minimum temperature, dewpoint, and evaporation. Solar radiation and maximum-minimum temperature play the most important role in the snowmelt simulation, and evaporation the least important.

Key parameters within the "lands" phase that are measured or determined by calibration are as follows:

EPXM = Interception storage parameter, which is a function of vegetative cover density

UZSN = The nominal storage parameter for upper zone and depressional storage, determined through calibration

LZSN	=	The nominal lower zone storage parameter, determined through calibration
K3	=	Index to actual evapotranspiration, which is a function of the area covered by forest or deep-rooted vegetation
INFIL	=	The infiltration parameter, which is a function of the soil characteristics
INTER	=	The parameter that sets the level of the interflow component of runoff
NN	=	Manning's "n" for overland flow
SS	=	Average overland flow slope

Figure 2 shows the sensitivity of total runoff to changes in these key parameters for a given watershed and storm event. Figure 3 shows the sensitivity of peak discharge to changes in the same parameters. It should be emphasized that these relationships are for one particular storm in a given watershed.

It would not be expected that these relationships would remain exactly the same for a different storm or in a different watershed. However, the relative sensitivity would be expected to remain approximately the same; i.e., the peak discharge is much more sensitive to LZSN than it is to EPXM. The relationship would change somewhat in examining the amounts of annual runoff. In this case, EPXM would be more significant than either NN, SS, or INTER.

Reliability

HSPF methodology, with minor variations in the channel routing, has been used successfully in more than 100 different applications over the past 10 years. It has been applied to small drainage basins and to extremely large drainage basins (Amazon River in Brazil). It has been applied to drainage basins with extreme variations in meteorological and climatological conditions.

The more difficult applications involved those basins in which snowmelt played a significant role in the late winter and early spring runoff. In most instances where representative meteorological records were available, the simulation results have been good. One shortcoming of the snowmelt algorithms is their inability to simulate frozen ground. When significant snowmelt occurs at the same time the ground is frozen, the model's infiltration algorithms are still operating; consequently, the resulting immediate runoff is

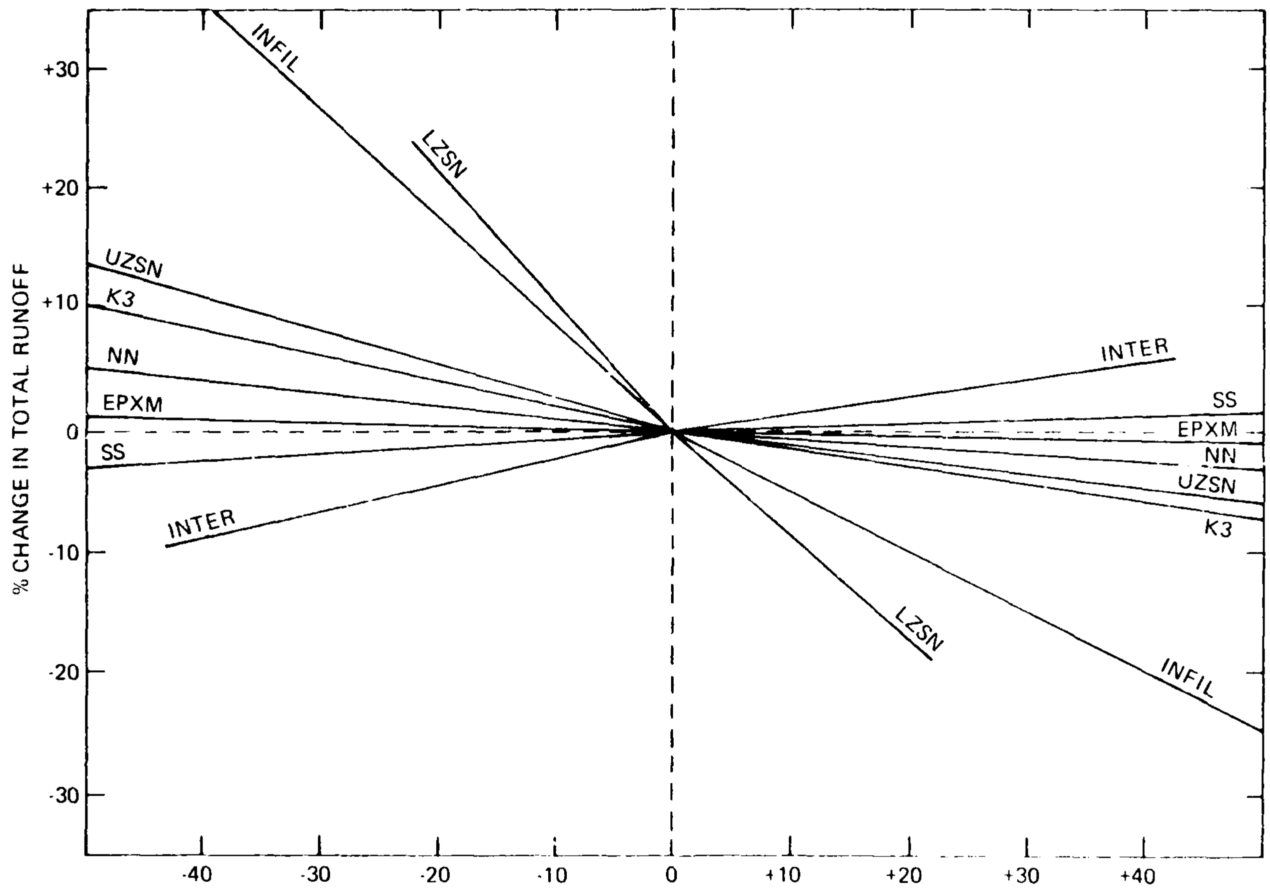

FIGURE 2
HYDROLOGY PARAMETER SENSITIVITY
TOTAL RUNOFF

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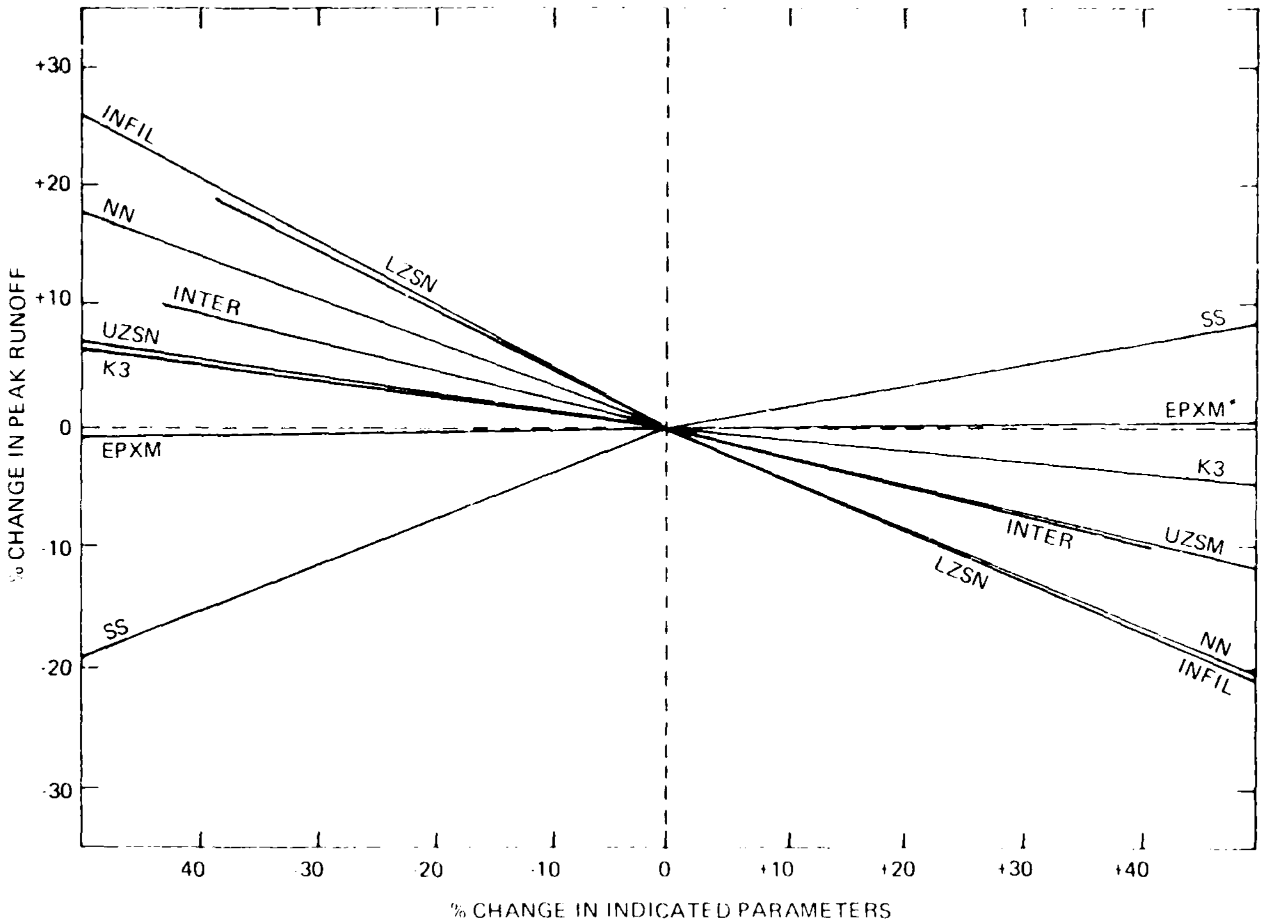

FIGURE 3
HYDROLOGY PARAMETER
SENSITIVITY PEAK RUNOFF

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undersimulated by the model. Figures 4, 5, and 6 show some snowmelt simulation results. Figure 4 is Cherry Creek near Denver, Colorado, for the period February 16, 1958 through March 30, 1958. The volume of runoff simulated was very close, but the timing of the runoff does not coincide. In this instance, the meteorological records were not representative of the condition that produced the actual runoff. Figures 5 and 6 show snowmelt events that were simulated in the Issaquah Creek watershed near Seattle, Washington. Simulation of volumes and timing was very good.

Overall, the reliability of applying the HSPF methodology will depend upon the quality of data series input to the model and the skill and experience of the individuals who are conducting the application.

Runoff and Routing Model (RROUT)

RROUT is a runoff and routing model that, in most respects, is similar to HSPF. The "LANDS" phase and snowmelt algorithms of both models are the same. RROUT was developed for application to flooding problems where continuous streamflow routing is not required. A significant cost savings is effected by only conducting channel routing for the two or three major events that occur each year as opposed to continuous routing that includes the low flow periods.

Computer Compatibility

The coding for RROUT, which includes the "lands" phase of the Stanford Watershed Model (SWM), is written in Standard ANSI Fortran IV. The program, as presently coded, is compatible with most computer systems including the University of Minnesota CYBERNET 74, North Dakota IBM 370/178, and Boeing Computer System. Only minor changes in the input/output specification are required between systems. As with HSPF, efficient operation of the programs requires the use of tape and disk devices.

Theory and Methodology

As indicated earlier, the basic theory underlying RROUT is the same as in HSPF for simulating runoff as overland flow, in the routing of the overland flow, and in simulating the accumulation and melt of the snowpack. Therefore, the description of those procedures will not be repeated. Figure 7 is a simplified flow chart of the RROUT logic.

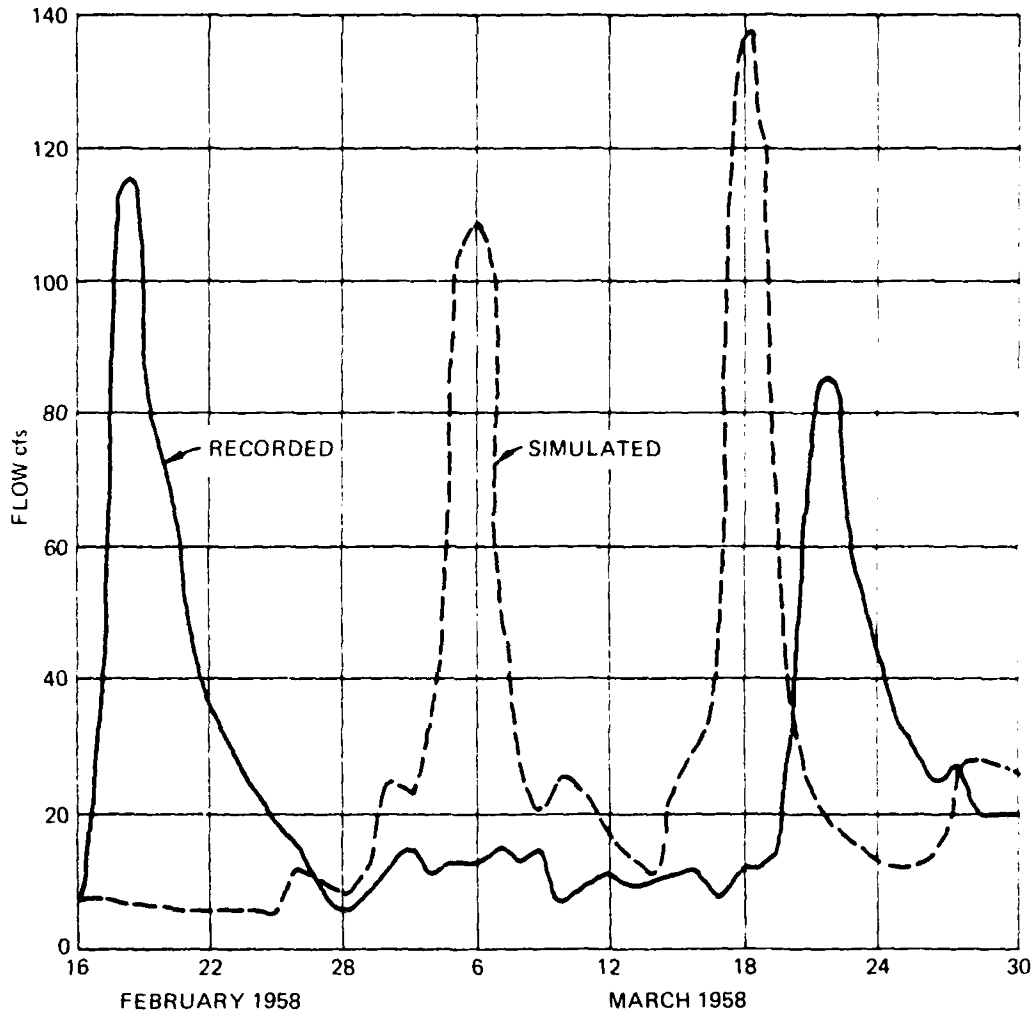

FIGURE 4
CHERRY CREEK WATERSHED
MEAN DAILY FLOWS

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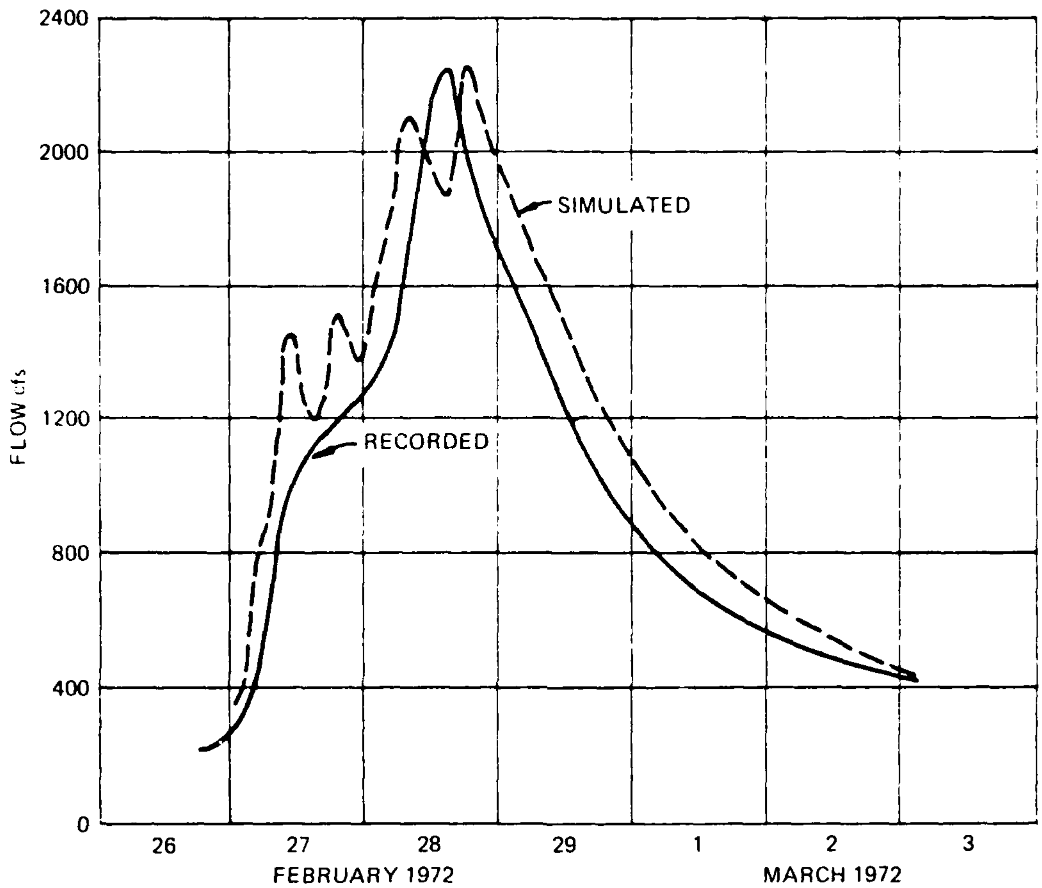

FIGURE 5
ISSAQUAH CREEK STORM HYDROGRAPH

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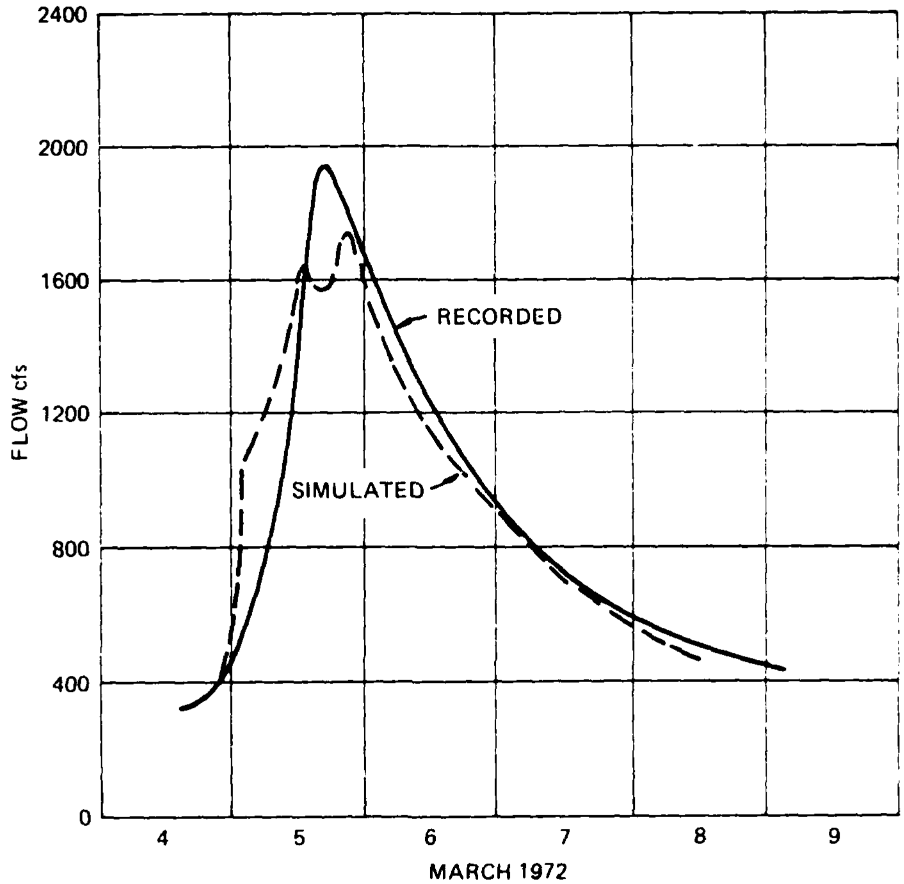

FIGURE 6
ISSAQUAH CREEK
STORM HYDROGRAPH

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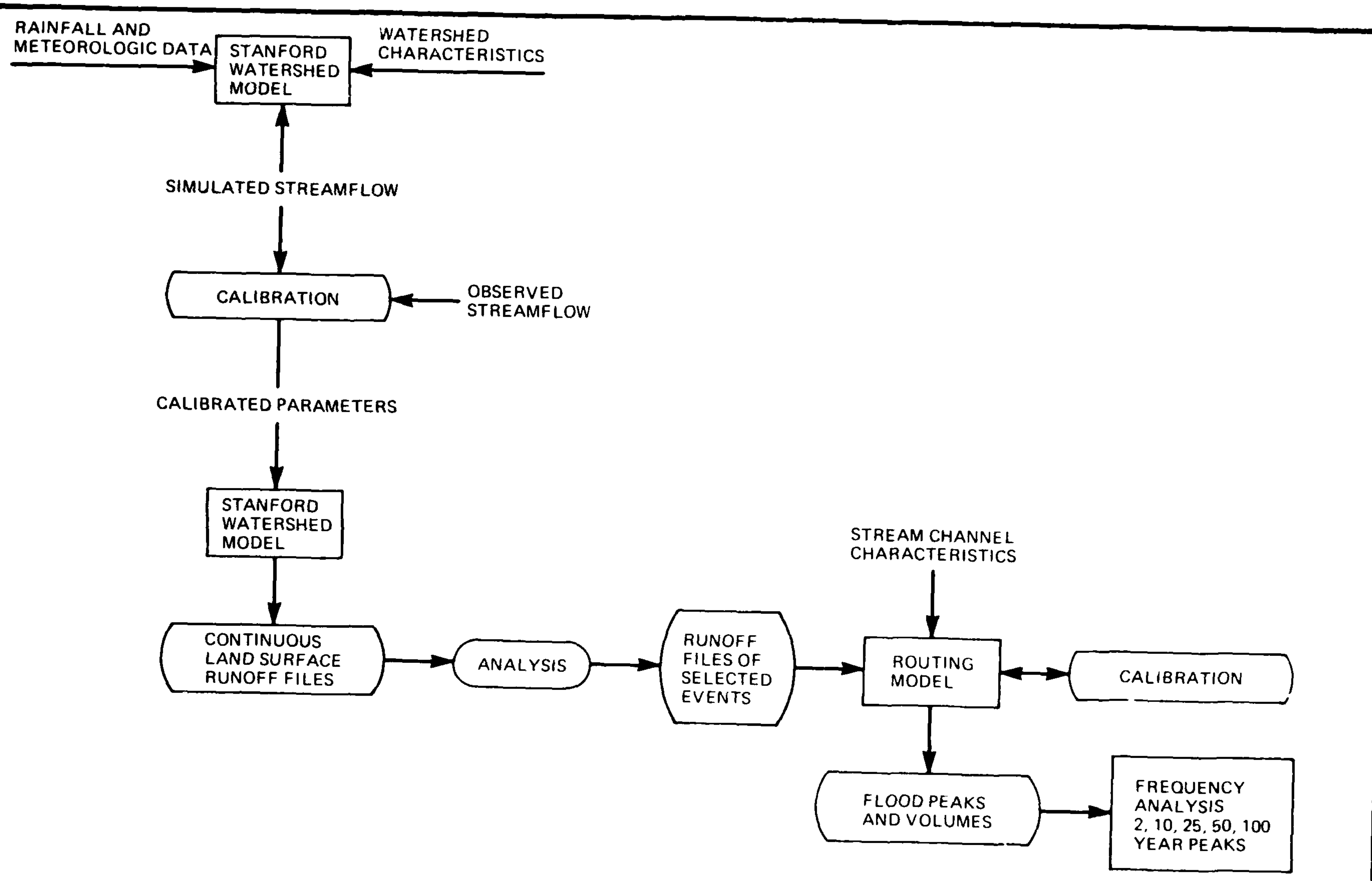

FIGURE 7
RROUT LOGIC

Channel and Reservoir Routing. RROUT uses a kinematic wave type of solution for channel routing in which a substitution is made for the momentum equation. The basic relationships are:

$$\frac{\delta A}{\delta t} + \frac{\delta Q}{\delta x} = q \qquad (7)$$

$$Q = aA^m \qquad (8)$$

in which

A = the cross sectional flow area,
Q = the rate of channel flow,
q = the rate of lateral inflow,
t = time,
x = the distance along the channel reach in the downstream direction, and
a,m = constants which are a function of channel slope, roughness, and size.

Equations (7) and (8) are solved simultaneously at each time step for the two unknowns, A and Q.

Reservoir storage routing is accomplished by using the basic continuity equation:

$$\frac{I_1 + I_2}{2} + \frac{O_1 + O_2}{2} = \frac{S_2 + S_1}{t} \qquad (9)$$

in which

I = inflow,
O = outflow,
S = storage,
t = time interval, and
1,2 = differing time frames.

In Equation (9) O_2 and S_2 are unknowns. The additional equation needed for a solution is the relationship between outflow and storage. This relationship can usually be developed from an analysis of the hydraulics of the geometry of the outflow section. If a mathematical relationship is not attainable, a table of storage versus discharge is used. In addition, a table relating storage volume to elevation is needed.

As with the routing procedures of HSPF, it is also unlikely that RROUT would yield good results on the mainstem of the Red River of the North.

Sensitivity Analysis

The runoff files of RROUT are produced with the same procedure as in the "LANDS" phase of HSPF; therefore, the same sensitivity description applies.

The channel routing results are very much dependent upon the values of a and m used in Equation (8). It is recommended that several values of the coefficients be tested against recorded streamflow in the area to determine which values are the most appropriate. The following table shows the sensitivity of peak flows to a with m equal to 1.25 for Camp Creek near Atlanta, Georgia.

PEAK FLOW (cfs)

Storm	a	Simulated	Measured
04/06/64	0.007	74.	1212.
	0.07	632.	1212.
	0.15	1250.	1212.
	0.20	1512.	1212.
04/27/64	0.007	91.	1488.
	0.07	761.	1488.
	0.15	1550.	1488.
	0.20	1927.	1488.
10/16/64	0.007	32.	548.
	0.07	262.	548.
	0.15	517.	548.
	0.20	633.	548.

It can be seen from these results that the value of a = 0.15 gives good comparison. Where possible, a similar type of sensitivity analysis should be conducted prior to application of RROUT.

Reliability

As previously mentioned, the "LANDS" phase of RROUT uses the same basic methodology as HSPF. This methodology has been used to provide estimates of land surface runoff in applications too numerous to mention (over 100). One certainty derived from these many applications is that when properly used, the methodology will produce very good results.

The stream channel routing methods in RROUT are not as well tested at the "LANDS" phase methods. However, the routing is a straightforward application of the well-known kinematic wave methodology. Figure 8 shows simulated flows versus measured for three runoff events that occurred in a small

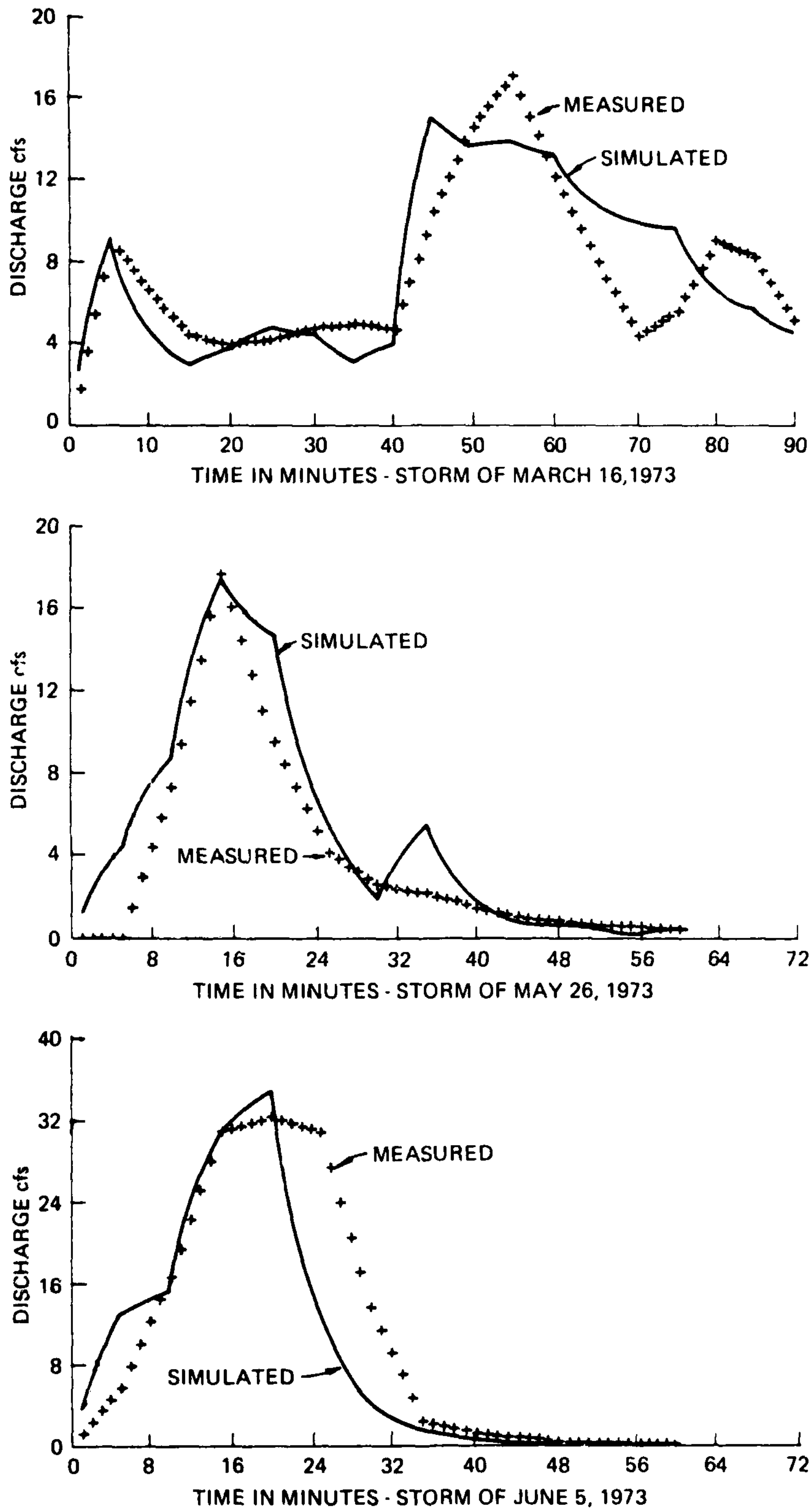

FIGURE 8
CLAIRMONT WATERSHED CALIBRATION RESULTS

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drainage basin near Atlanta, Georgia. It is expected that the channel routing would be adequate and produce reliable flow values for most of the tributaries to the Red River of the North.

Minnesota Model for Depressional Watersheds (MMDW)

Computer Compatibility

The MMDW was developed by Dr. Ian D. Moore at the University of Minnesota on the CYBERNET 74 (CDC) system between 1975-78. The program language used is standard Fortran IV and is compatible with most major manufacturer's equipment (compilers) including International Business Machines (IBM), Digital Equipment Corporation (DEC), Univac, and others. The model is designed as an in-core program using about 147K bytes of core and requiring a limited amount of auxiliary disk/tape storage. The climatological and meteorological data are saved on files which can be accessed as necessary by the main program at specified frequency, usually 1 month at a time.

Theory and Methodology

The MMDW is primarily a continuous simulation hydrologic model. The fundamental development is a physically based, measured parameter approach which is well suited for long-term, continuous modeling. The program can be set up to examine event-type responses within a basin on an hourly or more frequent time scale.

MMDW is comprised of four major subprograms called "snow," "land," "drainage," and "channel." Each of these submodels will be discussed in some detail; however, a more in-depth review of the governing equations and relationships can be found in "Effects of Drainage Projects on Surface Runoff from Small Depressional Watersheds in the North Central Region," Water Resources Research Center, University of Minnesota Bulletin 99, January 1979.

Snow Phase. The snow accumulation and snowmelt theory and methodology is based upon the principles of conservation of heat and energy. The basis of the algorithm used in the MMDW comes directly from the work of Dr. Eric Anderson (1968), with one minor modification. The MMDW allows for the optional use of an empirically dependent radiation quantity based upon cloud cover instead of sunshine duration. Otherwise, the snow phase algorithm of the MMDW is conceptually the same as that used by the Hydrocomp Simulation Program (HSP-1976) and the National Weather Service version of the Stanford Watershed Model.

The MMDW snow routine can be subdivided into a set of processes related to snowpack characteristics and mechanics. Major components considered are snowmelt due to radiation, condensation-convection melt, rain and ground melt from heat transfer, rainfall/snowfall, snowfall characteristics such as compaction and water content, and snowpack heat loss from back radiation. The development and form of these equations is presented in Anderson (1968) or Donigian and Crawford (1976).

Land Phase. The land section of the MMDW is subdivided into four main subroutines called interception, infiltration, redistribution, and evapotranspiration.

The interception is that amount of precipitation that is prevented from reaching the ground by vegetal cover. The MMDW treats this process as a moisture storage capacity of fixed amount. The surplus beyond this capacity is then available for other processes of the soil and rainfall interaction.

The infiltration process is one of the most critical phenomena in the determination of runoff. The water-soil transport processes in the MMDW are governed by the relationship called the characteristic curve, which relates matric potential and moisture content. The relative hydraulic conductivity is estimated from the subdivision of the soil characteristic curve, the measured (or reported) saturated moisture content, and the saturated hydraulic conductivity, using a technique presented by Jackson (1972) and Hillel and Bavel (1976).

Three cases of infiltration are considered in the MMDW at any point in time. They are rainfall intensity less than saturated conductivity, rainfall intensity greater than the infiltration capacity, and rainfall intensity greater than the saturated conductivity but less than the infiltration capacity. The infiltration resulting from each case or any combination of these three cases is described by modifying the Green-Ampt (1911) approach into a two-stage event proposed by Mein and Larson (1971, 1973). The two stages are before surface ponding and after surface ponding. Analytical solutions to the flow equation under each of these two conditions are presented by Mein and Larson (1971, 1973) and Moore (1979).

In the MMDW, the top 6-inch layer of the soil profile is used for control of the infiltration computations. The average moisture content of this layer is used in computing the moisture deficit and capillary suction at the wetting front. Variable flux boundary conditions are handled using a numerical technique which assumes the flux is constant within each discrete time interval. The basic time interval for infiltration events is 1 hour.

The infiltration algorithm requires matric-suction and relative conductivity data as functions of soil moisture content and basic soil properties. When the soil freezes, the hydraulic conductivity of the wetted zone is decreased to less than 1/20th of the normal value. The periods of soil freeze and thaw are predicted using an empirical relationship and maximum and minimum temperature data.

The process of soil water redistribution continues after runoff ceases in response to matric and gravitational forces. Other influencing factors such as thermal or concentration gradients can be significant in particular circumstances; however, in the MMDW approach, the thermal and concentration effects on redistribution are ignored. The redistribution rate decreases with time because the suction gradient between the wet and dry zones decreases as the moisture gradient decreases and the conductivity in the transmission zone declines with desorbtion.

In the MMDW, the soil profile is divided into 10 layers (each 6 inches thick) to a depth of 5 feet, and a single lower layer 5 feet thick, for a total depth of 10 feet. A subsurface tile drainage line (if one exists) is located at 4 feet. Water movement occurs in the soil profile in three steps. First, deep seepage occurs from the bottom of the soil profile according to a maximum rate specified as an input parameter. The actual deep seepage rate from the soil profile is a maximum at the fillable porosity of the lower soil layer, and decreases linearly to zero at field capacity.

Second, the infiltration is allowed up to the fillable porosity. If the complete soil profile fills up, no further infiltration is allowed until moisture is removed through evapotranspiration or tile drainage. The third step, redistribution between layers, is computed from the one-dimensional Darcy equation for unsaturated porous media. Negative or upward water movement is ignored. The redistribution scheme is carried out at a time increment equal to 1/6 the governing time step in the channel routing phase.

The evapotranspiration (ET) has an important role in determining the soil moisture distribution. The main factors affecting ET are the solar radiation and sunshine duration, as well as wind speed, vapor pressure, and growth and density of vegetation. Pan evaporation data are used in the MMDW for estimating potential ET during the growing season. The monthly pan coefficients used in the model are based upon the type of vegetation, stage of growth, and density of coverage. When a snowpack exists, the evaporation from the snow is computed from an equation in the snow phase which relates windspeed and pressure to the evaporation rate.

The effect of soil moisture on the relationship between actual and potential ET has several schools of thought. The MMDW model has used the approach of Holmes and Robertson (1963) that postulates that the critical point where plants begin to experience stress occurs somewhere between field capacity and wilting point. The actual ET is then generated from potential ET and pan evaporation information through the application of an ET ratio versus soil moisture curve. The ET ratio is the actual ET to potential ET.

Drainage Phase. This section of MMDW is used to account for the hydrology and hydraulics of depressional type watersheds. The topographic features of these flat, agricultural lands are characterized by numerous potholes of surface storage, lakes, and marshes. The travel time for overland flow in depressional watersheds is generally small in comparison to the time of travel from the depressions to the watershed outlet. For this reason, the MMDW neglects overland flow routing and assumes rainfall excess appears instantaneously as depressional inflow.

Several drainage conditions which occur in the region are considered:

1. Natural condition without artificial drainage
2. Surface drainage by shallow ditches
3. Surface drainage by tile mains with surface inlets
4. Subsurface drainage by tile networks
5. Complete drainage combining Option 4 with either Option 2 or Option 3

Elemental watersheds are defined and characterized by some form of drainage. The drainage network is operated on through the application of the continuity equation, Manning's flow equation, and empirically derived storage-depth function and depth-discharge (inflow) relations, depending upon the operational mode of the elemental watershed. The subsurface drainage component is based upon the two-dimensional analytical solution of the seepage equation with steady rainfall and homogeneous soil presented by Toksov and Kirkham (1961) and the continuity equation. The continuity equation applied to both surface and subsurface drainage is the same except for a submain flow term which appears in the subsurface drainage option to account for subsurface tile laterals.

Natural condition operation allows for surface storage of rainfall excess, but does not route the water as overland flow once the storage capacities are filled. The overflow then becomes a direct component of the total runoff within the watershed. This is most applicable to smaller watersheds with limited overland flow potential.

Channel Phase. The channel phase becomes increasingly important as the watershed size and type deviates greatly from the depressional topography. In small watersheds, the runoff is primarily governed by the land phase (and snow) with little impact from channel routing. However, for large watersheds the channel phase can dominate the stage and timing of the downstream flooding.

The basic equations for one-dimensional unsteady flow in open channels are the St. Venant equations as described below for continuity and momentum, respectively.

$$\frac{\delta Q}{\delta x} + \frac{\delta A}{\delta t} = q \qquad (10)$$

$$\frac{\delta y}{\delta x} + \frac{1}{g}\frac{\delta v}{\delta t} + \frac{v}{g}\frac{\delta v}{\delta x} + \frac{vq}{gA} = (So - Sf) \qquad (11)$$

where:

- A = Cross-sectional area
- v = Mean velocity
- Q = Mean discharge
- y = Depth of flow
- x = Distance coordinate along channel
- g = Gravitational acceleration
- t = Time
- q = Lateral inflow per unit of channel length
- S_o = Channel bed slope
- S_f = Energy slope (friction slope)

Because of the nonlinearities involved, the solution to these equations is not tractable for long-term continuous flow routing in channels. For the MMDW, a simplified quasi-dynamic routing method is substituted which replaces the momentum equation (11) with the normal discharge relation expressed as Manning's equation.

$$Q_n = \frac{1.486\ R^{2/3}\ S_0{}^{1/2} A}{n} \qquad (12)$$

This methodology simplifies the routing procedure considerably and reduces computer simulation time. The approach assumes:

$$1 - \frac{S_f}{S_0} << 1.0$$

and has been considered accurate for most watershed-type routing problems. The applicability to large mainstem river routing studies may be limited because of the lack of

detail in the momentum equation, as shown by Equation 12. The form of Equation 12 is substituted into Equation 10 and is solved in an iterative technique for the unknown discharge and flow area at the next time period. The hydraulic parameters for each subreach, such as geometry and roughness, are uniquely defined. All inflows generated from the runoff from each elemental watershed are assumed to be uniformly distributed along each subreach. Inflow at the head of each reach is described by the inflow hydrograph.

Storage routing through lakes and reservoirs is not presently an option in the MMDW program. Certain considerations in the depressional storage and drainage phase are available which act as a type of storage routing technique by virtue of the depth-volume relationships. However, these are not methods which are generally used in lakes and reservoirs in the more popular reservoir routing techniques. F r small lakes which resemble the depressional storage areas, the MMDW techniques for surface inlet (simulating outlet works) and depth-volume expressions would be adequate to account for a simple form of routing. This procedure would probably give an accelerated rate of discharge over the usual reservoir routing techniques because of the lack of time differentiation of inflow and outflow.

Data Requirements for Model Calibration

The MMDW is a measured parameter model which inherently requires a mimimal amount of calibration of parameters, given accurate watershed data which define the physical processes and relations. The greater the approximation of these measured data and the more extrapolation of data from one area to the next, then the more likely is the need for adjustments in these data or assumptions (calibration). Calibration need not be limited to the assignment of fitting parameters, but it can also relate to the quality and type of physical data.

The program described herein has had a limited number of "calibration" parameters built into the code. Only two model coefficients were fitted, although many physical data were derived from literature. The deep seepage loss rate and the steady-state infiltration rate were both adjustable parameters. In addition, the percentage distribution of the elemental watershed types was also considered an important data input which significantly impacted the runoff volume. These distributions for each watershed are determined through investigation of land use and topography. Because the routing procedures did not use the traditional coefficient routing methods, but instead relied on hydraulic parameters, there is no need to calibrate coefficients. However, even the "measured" data such as friction factors and uniformity of reach geometry could become calibration type data when

detailed analysis is performed. These types of information are, however, easily measured in the case of geometry, or readily described in the literature and from the field in the case of friction or roughness factors.

Sensitivity Analysis

The MMDW approach to the depressional watershed area has had limited application and cannot truly be said to have had a sensitivity analysis performed on the key watershed parameters. Because of the testing that has been done on the two watersheds in Minnesota, the model has shown some sensitivity of runoff volumes to the steady-state infiltration rate and deep percolation from the bottom soil layer. The major portion of the difference in the runoff volumes is attributable to snowmelt runoff and definition of antecedent soil conditions. The difficulties with snowmelt were expected to be due to the steady-state infiltration rate which directly impacts the relative hydraulic conductivity of the soil. This becomes important under winter conditions when the soil is completely or partially frozen. This parameter did not affect summer runoff in a significant manner.

The predictability of peak discharges for single events ranged from good to poor. The dependency on precise rainfall records and variability over the watershed was concluded to be the major limiting factor in reproducing short-term runoff peaks. Even when considering relatively small watersheds, it is felt that reliance on a single precipitation station is a potential source of error. Snowmelt and infiltration from snowmelt in regions with intermittent melt patterns has also been demonstrated to be a complex problem and a source of substantial error.

From discussions with the author of MMDW, the importance of detailed, geographically dependent precipitation patterns was significant. The impact of tile drainage considerations in the Red River of the North was conversely expected to be quite small. The soils data used to define the soil characteristic curves were also suggested as an important factor in the model. The infiltration and redistribution algorithms are directly dependent on these data. The development of several elemental watersheds with different soils characteristics, precipitation and climate, and drainage systems was expected to be important in the determination of local runoff peaks and volumes. About four elemental watersheds were used in the first application of the MMDW, which may have been limiting.

Reliability

The MMDW has been applied to two watersheds in southern Minnesota, both less than 20 square miles in area. The

comparison of simulated and observed runoff within the last 15 to 20 years showed a reproductive accuracy within 20 to 65 percent. Actual discharge records were compared graphically. Figures 9 and 10 are examples of results for both event-type and continuous simulation of the two watersheds in Minnesota. Generally, the continuous discharge results were reasonable when considering the lack of actual watershed data and the limited number of "calibration" runs. However, because the model is a measured parameter program, strict and complete information is required for size, type, and condition of the drainage systems, as well as the usual soil and hydrometeorological data. These data were often found lacking in the two watersheds tested.

The MMDW program appears to have a great deal of applicability and potential in depressional storage regions. Unfortunately, the reliability of reproducing historic events cannot be assessed sufficiently from the limited amount of model use.

The following table shows a brief comparison of results for the two watersheds tested.

SIMULATED AND ACTUAL RUNOFF COMPARISON

Year	Recorded Rainfall (in)	Recorded Annual Runoff (cfs)	Recorded Annual Runoff (in)	Recorded Annual Runoff (%)[a]	Simulated Runoff (in)	Difference: Simul.-Recorded (in)	Difference: Simul.-Recorded (%)[b]
Jackson County Ditch 11							
1957	29.08	753	3.64	12.5	2.92	-0.72	-20
1958	13.88	86	0.41	3.0	0.47	+0.06	+15
1959	34.20	584	2.83	8.3	2.76	-0.07	- 2
1960	34.14	952	4.61	14.8	5.47	+0.86	+19
Little Sioux River							
1959	34.20	658	1.43	4.2	1.51	+0.08	+ 6
1960	34.14	2789	6.07	19.5	3.45	-2.62	-43
1961	25.57	1022	2.22	8.7	0.73	-1.45	-65
1962	28.32	2825	6.14	21.7	2.96	-3.18	-52

[a]Percent of annual precipitation.

[b]Percent of recorded annual

The author of MMDW suggested that, had time permitted, a better historic fit could have been achieved through the

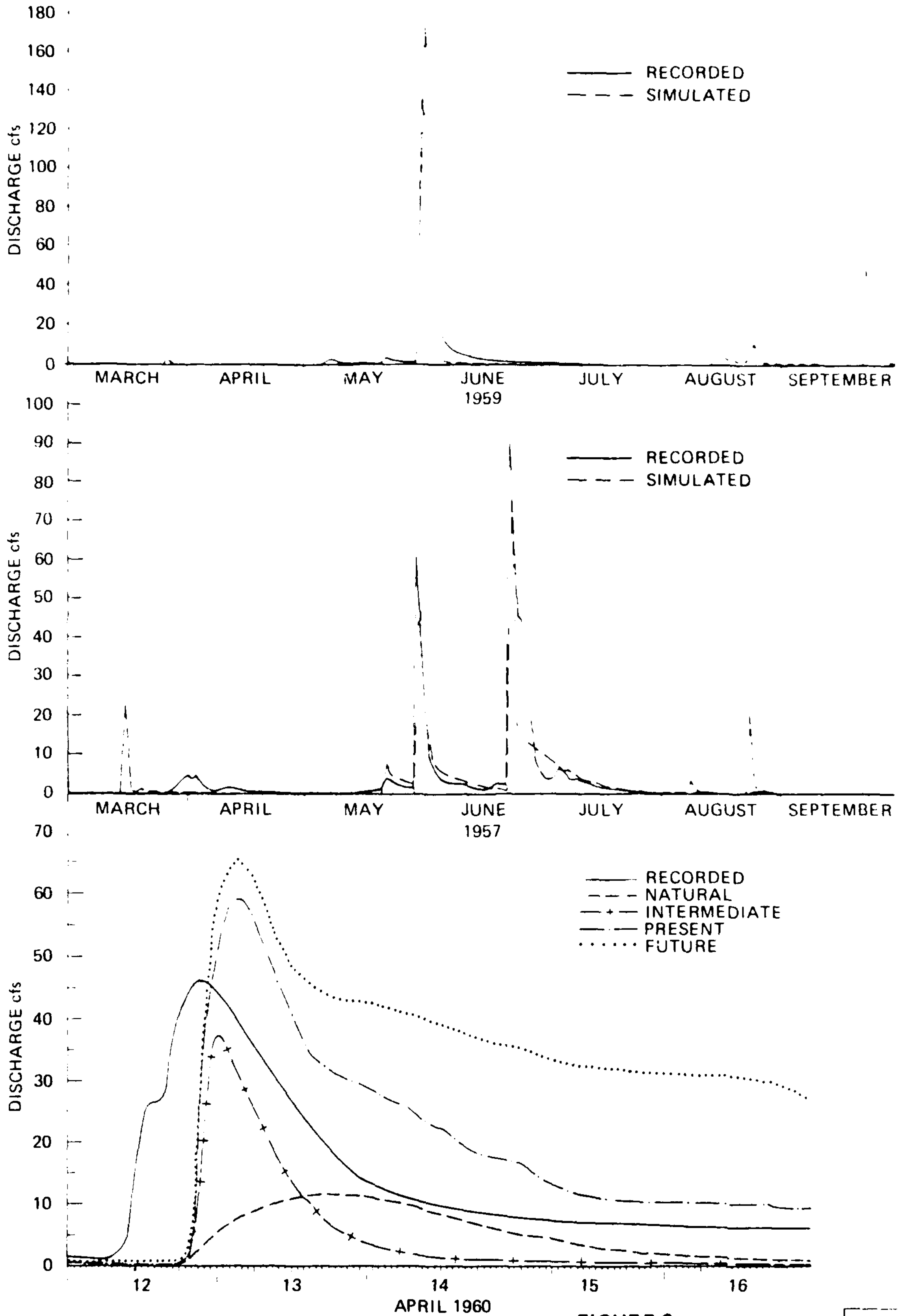

FIGURE 9
JACKSON COUNTY DITCH CALIBRATION RESULTS

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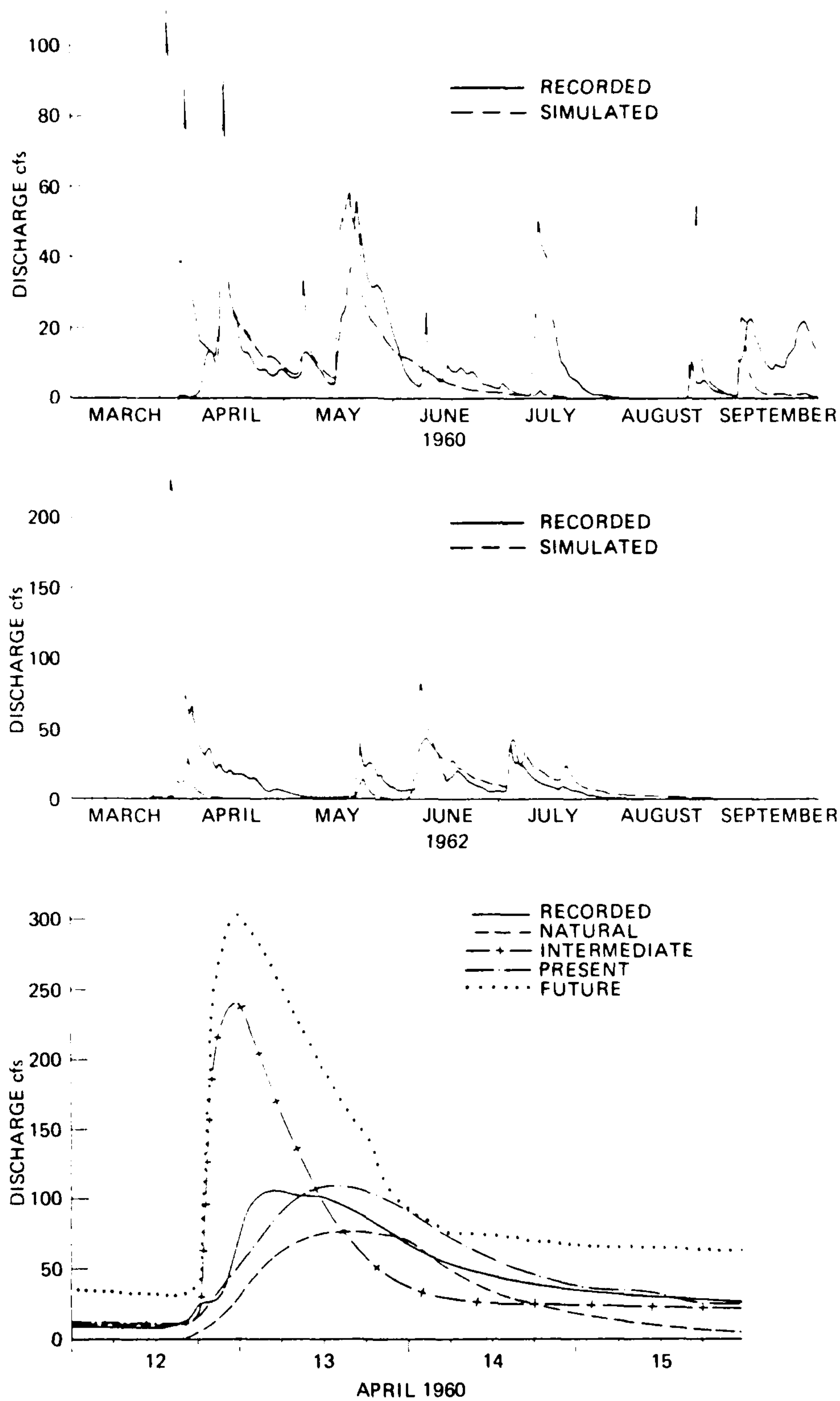

FIGURE 10
LITTLE SIOUX RIVER CALIBRATION RESULTS

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adjustment of the steady-state infiltration rate which was one of the two calibration-type parameters. This would not, however, have impacted the data reliability and its influence on the solution.

APPLICABILITY TO WETLAND AND DEPRESSION HYDROLOGY

The following discussion addresses the application of HSPF, RROUT and MMDW specifically in areas of wetland and depressional hydrology. However, it must be cautioned that any basin is composed only partially of wetland and depression areas. A model applied to any real basin must be able to simulate the hydrologic processes on the non-wetland, non-depressional areas as well. This is particularly important in larger basins where wetland and depressional areas comprise only a fraction of the total drainage area.

Hydrology

HSPF and RROUT

The hydrologic algorithms inherent in both HSPF and RROUT, i.e., the Stanford Watershed Model algorithms, have been applied to flat topography, wetland and depression areas throughout the world, including but not limited to:[1]

- Pinellas County, Florida: An area of mixed urban, agricultural and marshland characterized by flat terrain.
- Ingham County, Michigan: An urbanizing area presently in agricultural use and largely drained by field tile and ditches
- Clinton River Michigan: An urbanizing area characterized by low relief, extensive marshes and numerous small lakes
- Southeastern Wisconsin: Agricultural and urban watersheds in flat to rolling terrain with numerous marshes and lakes
- Northeastern Illinois: Urbanizing region with very flat, marshy terrain with streams characteristically broad and flat

[1] This list includes applicable studies with which CH2M HILL staff are most familiar. We are aware of other studies of extensive marsh and depressional areas, but are not as familiar with them.

Although the hydrologic algorithms of HSPF and RROUT do not explicitly represent the characteristics of marshes and depression areas, several of the model parameters describing land segment characteristics can be adjusted to represent those features which distinguish such topography. The Northeastern Illinois studies mentioned above provide a clear illustration of such parameter adjustments. For that study, each basin was described as a combination of four basic land types: lowland, cropland, grassland and impervious land. Table 2 shows how the parameters were adjusted between the various land types. The figures at the bottom of the table illustrate how these parameter variations affected the average annual runoff calculations.

The differences noted between lowland and cropland parameter values were initially based on a logical representation of the physical variations between the two land types and then refined and verified through calibration. The physical significance of the parameter variations is described below:

- Maximum interception storage, EPXM, is larger for lowland areas since tree and brush cover is significantly more extensive in marshland than in cropland.

- Nominal upper zone soil moisture, UZSN, is larger for lowland areas in order to represent shallow depression storage and soils with high water holding capacity. Water stored in this zone is subject to evapotranspiration and percolation. Larger depression storage areas may be represented as small reservoirs in either HSPF or RROUT.

- Actual evapotranspiration rate, K3, is higher for lowland areas because of greater vegetative cover as well as near surface storage of water.

- Deep groundwater seepage, K24L, is higher for lowlands since near surface ponding and poor surface drainage prolongs the period when infiltration and percolation is possible. For croplands underlain by field drains, this percolation would be intercepted and carried to surface streams.

- Evaporation from perched groundwater, K24EL, is higher in lowlands where muck deposits and poor surface drainage hold water near the surface.

- Infiltration factor, INFILTRATION, is lower in lowland areas as a result of soil clogging from organic deposits.

TABLE 2

CALIBRATED HYDROLOGIC PARAMETERS[1]
DES PLAINES RIVER, ILLINOIS
ANTIOCH RAIN GAGE

Parameter	Meaning	Parameter Values by Cover Type			
		Impervious	Grassland	Crop	Lowland
K1	Ratio of segment to gage rainfall	1.00	1.00	1.00	1.00
A	Impervious area fraction	0.99	0.00	0.00	0.00
EPXM	Maximum interception storage	0.10	0.12	0.10	0.20[2]
UZSN	Nominal upper zone soil moisture	1.10	1.10	1.10	6.00[2]
LZSN	Nominal lower zone soil moisture	7.50	7.50	7.50	7.50
K3	Actual evaporation rate parameter	0.30	0.25	0.30	0.90[2]
K24L	Seepage to deep groundwater	0.08	0.08	0.08	0.15[2]
K24EL	Evaporation from perched groundwater	0.04	0.08	0.04	0.15[2]
INFIL-TRATION	Infiltration factor	0.02	0.015	0.02	0.007[2]
INTER-FLOW	Interflow factor	2.50	2.50	2.50	3.50[2]
L	Length of overland flow	250	250	250	100[2]
SS	Overland flow slope	0.01	0.01	0.01	0.00[2]
NN	Manning's "n" for overland flow	0.08	0.25	0.08	0.35[2]
IRC	Daily interflow recession rate	0.50	0.50	0.50	0.50
KV	Groundwater recession, variable	1.00	1.00	1.00	1.00
KK24	Groundwater recession, constant	0.98	0.98	0.98	0.99
Average Annual Runoff (simulated) inches		29.36	13.00	12.31	6.16
in/in precipitation		0.82	0.36	0.34	0.17

[1] Source: HYDROCOMP, 1977.
[2] Parameter values significantly different between lowland and cropland.

- Interflow factor, INTERFLOW, is high in wetland areas due to saturated near surface soil layers. This factor may also be high in areas underlain by tile drains.

- Length of overland flow, L, is usually shorter in wetland areas, since surface water bodies are closely spaced in these areas. This factor may be measured from topographic maps.

- Overland flow slope, SS, is measured from topographic maps and is usually very close to zero in marshland, while in the Des Plaines basin, croplands commonly have some slope. In the Red River of the North, cropland slopes may also be measured at near zero.

- Manning's "n" for overland flow, NN, is assumed to be higher for wetlands where vegetation is thicker than on cropland.

As implied in the preceeding discussion, most of these parameter values are originally estimated and later calibrated rather than being directly measurable. Broad experience in calibrating the Stanford Watershed Model algorithms to low relief basins in the upper midwest enables good prediction of the required parameter values to be achieved without extensive calibration.

Documented calibration results are not presently available for all of the applications cited at the beginning of this section. However, the persons applying the models in each of these low relief areas found the results suitable for planning purposes. More detailed calibration results for the Des Plaines River basin in northeastern Illinois are provided in the water balance comparisons of Tables 3 through 7 and the frequency analysis of Figure 11. Further examples are provided in the Southeastern Wisconsin Regional Planning Commission Planning Report #26, Comprehensive Plan for the Menomonee River Watershed (1976).

The preceeding discussion indicates that the hydrologic algorithms of HSPF and RROUT have been used to adequately represent low relief marshland, depressional areas and cropland. Whether the models are "capable of determining the effect, past, present and future loss or addition of wetland and temporary storage areas has had and will have. . ." is largely a result of the model's ability to properly represent these areas and to properly represent the alternative uses to which this land may be put. In an ideal study, a model would be calibrated for a "natural" basin and for an otherwise similar basin which had been drained and the effect of drainage on model parameters would be directly verified.

TABLE 3

DES PLAINES RIVER
DES PLAINES RIVER AT GURNEE
(drainage area = 232 sq mi)
ANNUAL WATER BALANCE

CALIBRATION

Year	Simulated Runoff Annual (in)	Recorded Runoff Annual (in)	Difference (Simul.- Rec.) (in)	(%)[1]
1968 - 1969	10.80	11.18	-0.38	-3
1969 - 1970	11.96	8.21	+3.75	+46
1970 - 1971	10.51	10.60	-0.09	-1

VERIFICATION

Year	Simulated Runoff Annual (in)	Recorded Runoff Annual (in)	Difference (Simul. - Rec.) (in)	(%)[1]
1971 - 1972	17.94	16.36	+1.58	+10
1972 - 1973	17.10	17.77	-.67	-4
1973 - 1974	21.03	20.72	+0.31	+1

[1]percent of recorded annual runoff

Source: Adapted from HYDROCOMP, 1977

TABLE 4

DES PLAINES RIVER
BUFFALO CREEK
(drainage area = 19.6 sq mi)
ANNUAL WATER BALANCE

CALIBRATION

YEAR	Simulated Runoff Annual (in)	Recorded Runoff Annual (in)	Difference (Simul. - Rec.) (in)	(%)[1]
1964 - 1965	11.35	13.89	-2.54	-18
1965 - 1966	13.10	14.22	-1.12	-8
1966 - 1967	15.65	12.88	+2.77	+22
1967 - 1968	10.27	6.74	+3.53	+52
1968 - 1969	11.77	14.88	-3.11	-21

VERIFICATION

Year	Simulated Runoff Annual (in)	Recorded Runoff Annual (in)	Difference (Simul. - Rec.) (in)	(%)[1]
1969 - 1970	14.48	18.70	-4.22	-22
1970 - 1971	7.78	9.40	-1.62	-17
1971 - 1972	20.46	19.70	+0.76	+4
1972 - 1973	19.70	18.32	+1.38	+8
1973 - 1974	20.69	21.86	-1.17	-5

[1]percent of recorded annual runoff

Source: Adapted from HYDROCOMP, 1977.

TABLE 5

DES PLAINES RIVER
McDONALD CREEK
(drainage area = 7.93 sq mi)
ANNUAL WATER BALANCE

CALIBRATION

Year	Simulated Runoff Annual (in)	Recorded Runoff Annual (in)	Difference (Simul. - Rec.) (in)	Difference (Simul. - Rec.) (%)[1]
1964 - 1965	12.86	10.31	+1.25	+12
1965 - 1966	11.20	11.82	-0.62	-5
1966 - 1967	13.79	12.06	+1.78	+14
1967 - 1968	7.88	6.83	+1.05	+15
1968 - 1969	12.25	12.15	+0.10	+1

VERIFICATION

Year	Simulated Runoff Annual (in)	Recorded Runoff Annual (in)	Difference (Simul. - Rec.) (in)	Difference (Simul. - Rec.) (%)[1]
1969 - 1970	13.84	17.00	-3.16	-18
1970 - 1971	8.11	8.19	-0.08	-1
1971 - 1972	16.72	21.09	-4.37	-21
1972 - 1973	15.70	14.68	+1.02	+7
1973 - 1974	16.86	17.47	-0.61	-3

[1]percent of recorded annual runoff

Source: Adapted from HYDROCOMP, 1977.

TABLE 6

DES PLAINES RIVER
DES PLAINES RIVER NEAR DES PLAINES
(drainage area = 360 sq mi)
ANNUAL WATER BALANCE

CALIBRATION

Year	Simulated Runoff Annual (in)	Recorded Runoff Annual (in)	Difference (Simul. - Rec.) (in)	(%)[1]
1967 - 1968	6.47	3.96	+2.51	+63
1968 - 1969	9.85	11.36	-1.51	-13
1969 - 1970	12.69	10.53	+2.16	+20
1970 - 1971	9.58	10.01	-0.43	-4

VERIFICATION

Year	Simulated Runoff Annual (in)	Recorded Runoff Annual (in)	Difference (Simul. - Rec.) (in)	(%)[1]
1971 - 1972	18.45	16.40	+2.05	+12
1972 - 1973	18.59	18.24	+0.35	+2
1973 - 1974	20.78	21.12	-0.34	-2
Total	96.41	91.62		

[1]percent of recorded annual runoff

Source: Adapted from HYDROCOMP, 1977.

TABLE 7

DES PLAINES RIVER
LONG RUN
(drainage area = 20.9 sq mi)
ANNUAL WATER BALANCE

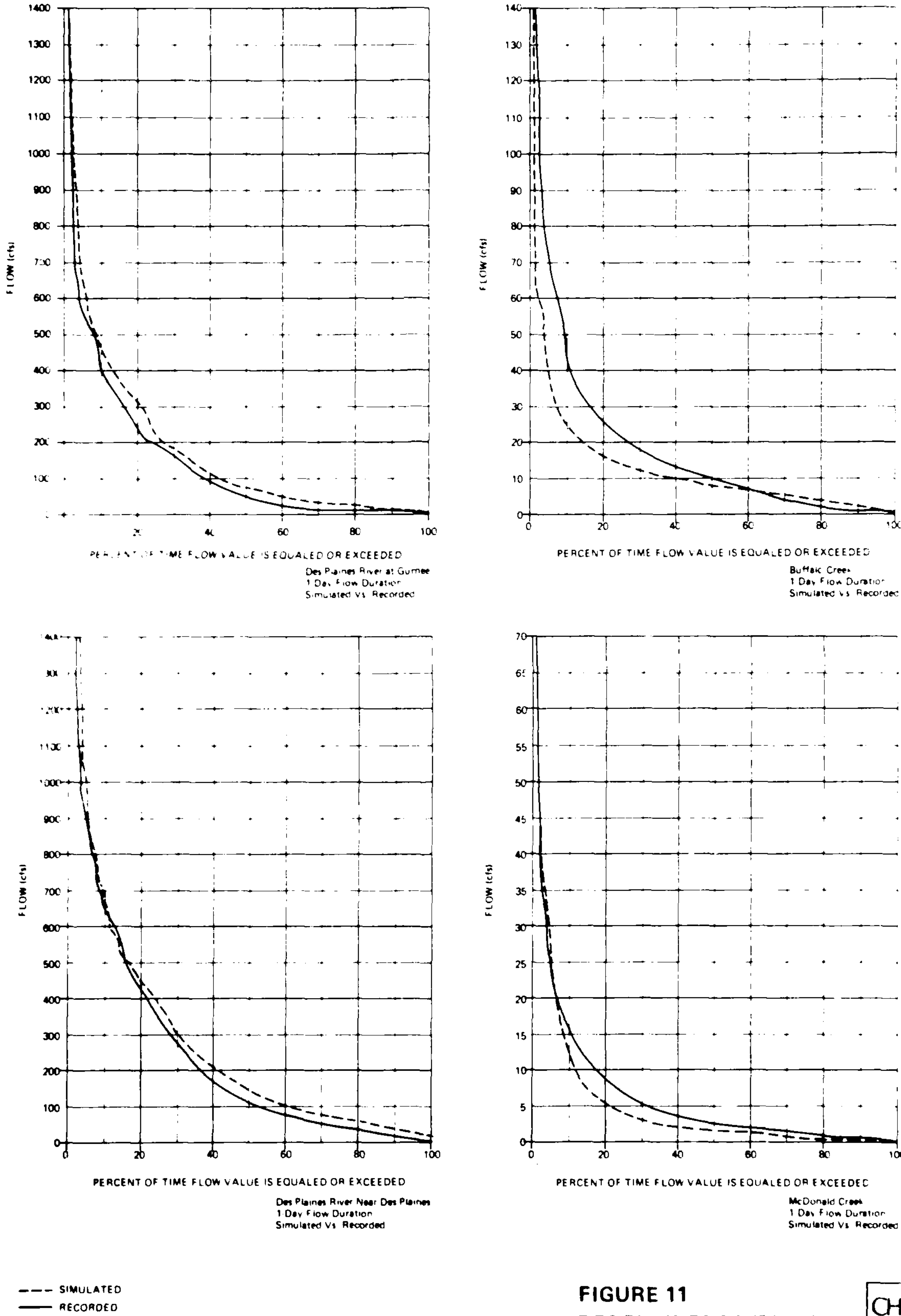
Year	Simulated Runoff Annual (in)	Recorded Runoff Annual (in)	Difference (Simul. - Rec.) (in)	Difference (Simul. - Rec.) (%)[1]
1964 - 1965	8.33	10.69	-2.36	-22
1965 - 1966	13.08	13.12	-0.04	0
1966 - 1967	9.80	11.21	-1.41	-12
1967 - 1968	10.23	9.40	+0.83	+9
1968 - 1969	10.34	9.27	+1.07	+12

VERIFICATION

Year	Simulated Runoff Annual (in)	Recorded Runoff Annual (in)	Difference (Simul. - Rec.) (in)	Difference (Simul. - Rec.) (%)[1]
1969 - 1970	11.83	13.27	-1.44	-11
1970 - 1971	7.71	7.67	+0.04	0
1971 - 1972	9.44	9.25	+0.19	+2
1972 - 1973	17.50	14.51	+2.99	+21
1973 - 1974	19.94	16.34	+3.60	+22

[1]percent of recorded annual runoff

Source: Adapted from HYDROCOMP, 1977.



Source: Hydrocomp 1977

FIGURE 11
DES PLAINES RIVER BASIN CALIBRATION RESULTS

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However, the ideal data are seldom available. The approach used in northeastern Illinois and elsewhere, that of calibrating one or more basins composed of varying combinations of the land types of interest, is more common and has been found to be useful in analyzing the effects of land type changes. The northeastern Illinois studies predicted the effects of urbanization by converting wetland and cropland areas to impervious and grassland areas in the model representation. Drainage of wetlands in the Red River of the North basins could be similarly represented by converting wetland areas to cropland or other appropriate uses.

MMDW

The MMDW model was developed specifically for the analysis of flat topography, wetlands and depression areas. The model explicitly addresses those characteristics unique to such physiography, including: soil moisture and drainage, depression storage, and tile drains.

The model algorithms have been tested on two small (less than 20 square mile) basins. Results of these tests are fair to good. However, since the model has experienced only limited testing and since this testing has been limited to small basins, its ability to represent conditions in the Rush River or other tributaries of the Red River of the North is uncertain. Its applicability to wetland and depressional basins larger than 20 square miles may be limited by the inability to simulate overland flow routing and by the detailed soils and depression data required for model input. The latter limitation could be overcome by generalizing the soils and depression characteristics of a larger basin. However, this would compromise the model's explicit representation of such phenomenon and its application history on basins where detailed data were available would be even less pertinent.

The MMDW model, as a result of its explicit representation of depression storage and subsurface drains, can be adjusted to represent changing wetland drainage conditions. However, it's application for such analysis requires detailed data and has not been extensively tested.

Stream Hydraulics

All three models utilize some version of kinematic wave analysis for stream routing. The current version of the HSPF channel routing algorithms differs from that used in previous versions of HSP and has not been widely tested. It requires the use of another simple model, or extensive hand

calculation, to develop depth-discharge relationships for input. Nevertheless, applications in the Clinton River, Michigan, indicate the algorithms produce reasonable hydrographs.[2] The routing algorithms of RROUT are similar to the dynamic routing of previous HSP versions and have been extensively tested where HSP dynamic routing was employed, as well as in applications of the RROUT forerunner, Georgia Tech's UROS, and in RROUT applications. MMDW algorithms have been specifically tested in only a limited number of basins, but since these algorithms are similar to those in HSP and RROUT, they should prove reliable in a number of situations.

Hydraulic routing algorithms of all the models have been successfully tested in low gradient streams. Nevertheless, the kinematic wave assumptions could not be expected to provide adequate results in analysis of the mainstem of the Red River of the North. Analysis of the mainstem would require a more sophisticated analysis tool such as DWOPER.

SUITABILITY FOR SMALL DRAINAGE SUBBASINS

In analysis of small drainage subbasins (40 to 80 acres), the stream routing algorithms are relatively unimportant since channel flow times are short. Hence, determination of which model is best suited to small basin analysis should concentrate on the hydrologic and land runoff algorithms of the models.

As previously stated, HSPF and RROUT utilize essentially the same hydrologic algorithms, i.e., those of the Stanford Watershed Model. Their ability to reproduce historic runoff from low relief areas is documented for several basins; however, the smallest of these is 7.93 square miles in drainage area. The algorithms have been tested on much smaller basins, even on single fields (Crawford and Donigian, 1973 and 1976). However, the documentation does not indicate whether these small basins were characterized by low relief, depressional hydrology.

The algorithms of HSPF and RROUT are established on a unit area basis and should be accurate for any small basin where stream routing is negligible. Since HSPF has better data management capabilities, it might be considered marginally easier to set up and manipulate than RROUT or MMDW for very small basin studies. However, this advantage is minimal in basins where the small areas are represented by a limited data base. Also, any advantage gained through HSPF's data handling routines would be counterbalanced by the need to

[2] From conversations with Norm Crawford, Hydrocomp, and Jim Ridgeway, Johnson and Anderson.

modify HSPF's half-word storage for installation on a computer system which lacks the half-word option. In many applications, HSPF's LANDS formulation may be more expensive to run than the Stanford Watershed Model.

MMDW algorithms have been tested only on basins of 7.69 and 17.1 square miles. Theoretically, they should be applicable to smaller basins, but this assumption has not been tested.

In view of the above, HSPF may be considered a slightly more suitable model for analysis of small watersheds (40-80 acres) using a computer with half-word capability. If the computing facilities do not have half-word capability, RROUT would be the model of choice. MMDW cannot be recommended for small watershed analysis until further testing proves it's applicability.

DATA REQUIREMENTS AND AVAILABILITY

Pertinent hydrologic, meteorologic and physiographic data available for hydrologic simulation of the Rush River are detailed in Table 8. Further discussion of the data available in this basin and in the Marsh Creek area is provided in Appendix D. In general, it can be stated that data available in the Rush River basin are more extensive than usually encountered in hydrologic simulation studies.

Tables 9, 10, and 11 provide a description of data requirements for the application of HSPF, RROUT and MMDW, respectively. Each table summarizes model data requirements, available data to meet these requirements, additional data which must be acquired in order to utilize each model in a manner consistent with its previous applications, and a rough estimate of the labor, data and computer costs involved in gathering, coding, correcting and manipulating the data into the form required for actual model operation.

The data requirments are consistent with previous applications of the respective models. Collection of additional data, particularly additional calibration data (streamflow data near the mouth of the river, runoff data from a small depressional basin, hourly precipitation at Amenia, etc.), would increase model reliability. Collection of less data may not adversely affect the model's ability to reproduce historic hydrographs, particularly with respect to the soils and depression data required for MMDW. However, that model has not been tested for more generalized data input.

The costs figures presented are estimates based primarily on experience gained in numerous applications of HSP and RROUT algorithms and interpretation of the data requirements and extrapolation of the data costs for MMDW application. HSPF

TABLE 8

AVAILABLE DATA
RUSH RIVER BASIN

Data Series	Source Agency	Location	Format of Available Data	Period of Record
Streamflow Records	U.S. Geological Society	Rush River at Amenia, ND	Daily data published or magnetic tape. Continuous data available as recorded	7/46 - present
Hourly Precipitation	NOAA - National Weather Service	Fargo, ND	Published or magnetic tape	1930 - pres.
		Wahpeton, ND	"	1891 - pres.
		Valley City, ND	"	1935 - 1940
		Grand Forks, ND	"	1934 - pres.
Daily Precipitation	NOAA - National Weather Service	Chaffee, ND	"	1961 - pres.
		Amenia, ND	"	1948 - pres.
		Colgate, ND	"	1933 - pres.
		Grand Forks, ND	"	1890 - pres.
		Georgetown, MN	"	1961 - pres.
		Wahpeton, ND	"	1891 - pres.
		Fargo, ND	"	1880 - pres.
Temperature	NOAA National Weather Service	Amenia, ND	"	1948 - pres.
		Colgate, ND	"	1962 - pres.
		Grand Forks, ND	"	1890 - pres.
		Fargo, ND	"	1880 - pres.
		Wahpeton, ND	"	1891 - pres.
		Georgetown, MN	"	1961 - pres.
Dew Point Temperature	NOAA National Weather Service	Fargo, ND	"	1970 - pres.
Wind Data	"	"	"	1970 - pres.
Sunshine	"	"	"	1970 - pres.
Radiation	"	Bismarck, ND	"	1970 - pres.
Evaporation	"	Fargo, ND	"	1970 - pres.
Snow Data	"	"	"	1970 - pres.
	C.O.E.	St. Paul, MN	?	?
Soils Data	U.S. Soil Conservation Svc.	Cass Co., ND	Unpublished until 1981-82	-
		Traill Co., ND	Published	-
Topography	U.S. Geological Survey	15-minute quadrangle topo. maps	Published maps	Varies
	U.S. Soil Conservation Svc.	See soils	Soils maps	
Vegetation	EROS Data Ctr.	LANDSAT and U-2 photos	Unpublished	Varies
	U.S. Forest Svc.	Statewide Woodland Inventory	To be published	1980
Geology	ND Geological Survey	Geology & groundwater of Cass Co.	Published bulletin	-
	"	Physical Data	Published	-
Land Use	ND Geological Survey	Maps from LANDSAT	1:125000 scale maps	-

TABLE 9
HSPF DATA NEEDS

Data Needs	Available Data	Additional Data Required*	Estimated Cost**
Meteorologic Data			
Hourly Precipitation	Fargo Wahpeton Valley City Grand Forks Chaffee**** Amenia**** Colgate**** Georgetown****	none	$ 1,500
Daily Maximum and Minimum Temperature	Amenia Colgate Grand Forks Georgetown Fargo Wahpeton	none	500
Daily Dewpoint Temperature	Fargo Bismarck	none	200
Daily Wind	Fargo Bismarck		100
Daily Sunshine	Fargo Bismarck		100
Daily Solar Radiation	Bismarck can be supplemented by estimates from sunshine	none	200
Semimonthly Evaporation	Fargo can be supplemented by estimates from temperature, dewpoint temperature, wind and radiation	none	300
Calibration Data			
Snow, general depth and cover	Fargo Corps of Engineers	none	100
Streamflow records	Rush River at Amenia	none	300
Land Data			
Topography	USGS topographic maps soils maps	none	100
Land use and cover	EROS imagery U.S. Forest Svc. Maps Geological Survey	none	1,500
Soils, general characteristics	Soil Surveys	none	250
Stream Data			
Length	USGS topographic maps		100
Slope	"		150
Cross section	none	field survey	9,000***
Roughness	none	field survey &	1,500
TOTAL ESTIMATE			$15,900

* Indicates minimum data requirements for calibration, verification and application. Further data would be useful but not necessary.

** Rough estimate of cost to collect, code, correct, manipulate and input data for the Rush River drainage basin in the form required by the model.

*** This cost will be somewhat higher if detailed cross sections suitable for future floodplain delineation are required.

**** Daily data can be distributed.

TABLE 10
RROUT DATA NEEDS

Data Needs	Available Data	Additional Data Required*	Estimated Cost**
Meteorologic Data			
Hourly Precipitation	Fargo	none	$ 2,500
	Wahpeton		
	Valley City		
	Grand Forks		
	Chaffee***		
	Amenia***		
	Colgate***		
	Georgetown***		
Daily Maximum and Minimum Temperature	Amenia	none	600
	Colgate		
	Grand Forks		
	Georgetown		
	Fargo		
	Wahpeton		
Daily Dewpoint Temperature	Fargo	none	250
	Bismarck		
Daily Wind	Fargo	none	150
	Bismarck		
Daily Sunshine	Fargo	none	150
	Bismarck		
Daily Solar Radiation	Bismarck can be supplemented by estimates from sunshine		300
Semimonthly Evaporation	Fargo can be supplemented by estimates from temperature, dewpoint temperature, wind and radiation	none	400
Calibration Data			
Snow, general depth and cover	Fargo	none	100
	Corps of Engineers		
Streamflow records	Rush River at Amenia	none	300
Land Data (SAME AS HSPF)			1,850
Stream Data			
Length	USGS topographic maps		100
Slope	" " " " "		150
Cross section	" " " " "		8,000
Roughness	" " " " "		1,500
TOTAL ESTIMATE			$16,450

* Indicates minimum data requirements for calibration, verification and application. Further data would be useful but not necessary.

** Rough estimate of cost to collect, code, correct, manipulate and input data for the Rush River drainage basin in the form required by the model.

*** Daily data can be distributed.

TABLE 11
MMDW DATA NEEDS

Data Needs	Available Data	Additional Data Required*	Estimated Cost**
Meteorologic Data (SAME AS RROUT)			$ 4,350
Calibration Data (SAME AS RROUT)			400
Land Data			
Topography	USGS topographic maps soils maps	drainage plans & field inspection	2,000
Land use and cover	EROS imagery U.S. Forest Svc. Maps Geological Survey	none	1,500
Soils, including moisture characteristics	Soil Surveys	field sampling & cores testing	10,000
Surface depression & drainage data		field survey	8,000
Stream Data (SAME AS HSP)			10,750
TOTAL ESTIMATE			$37,000

* Indicates minimum data requirements for calibration, verification and application. Further data would be useful but not necessary.

** Rough estimate of cost to collect, code, correct, manipulate and input data for the Rush River drainage basin in the form required by the model.

meteorologic data costs are somewhat lower than those for RROUT and MMDW since the HSPF package contains an extensive data handling system which simplifies data preparation.

Data requirements for the three models are similar with the notable exception that MMDW requires more soils and depression/drainage information. Data compilation costs would be slightly lower for HSPF and significantly higher for MMDW.

The preceeding discussion has focused on data availability in the Rush River. The Rush River basin has a more comprehensive data base than that usually available for hydrologic simulation studies. The HSP and RROUT methodologies have frequently been successfully applied to basins where available data were far more limited.

The minimum data requirements for application of this methodology are:

- o Representative meteorologic data - available throughout North Dakota and Minnesota in detail suitable for planning studies. More site specific data may be required for research studies on small basins.

- o Topographic data - available throughout North Dakota and Minnesota from USGS topographic maps.

- o Land cover data - available nationwide through satellite imagery, though use of this data source alone would require some ground truthing. Most areas in the United States have additional land cover data available from planning agencies, aerial photos and other studies. In some cases, HSP and RROUT methodologies have been successfully applied with windshield survey and discussion with local residents as the only land cover data source (e.g., Ingham County, Michigan).

- o Channel hydraulics data - seldom available at the outset of any hydrologic/hydraulic analysis, but necessary for the application of any realistic methodology.

These basic data requirements are met throughout the Red River of the North Drainage Basin. Since the Stanford Watershed Model inherent in both HSPF and RROUT requires some parameter values that cannot be directly measured, it is desirable to also have available streamflow records against which the models can be calibrated. Any model should be calibrated and/or verified against local records prior to use. However, model parameters can be selected from experienced judgment where calibration data are lacking.

This technique has been tested in several multibasin studies (the previously mentioned Northeastern Illinois and Southeastern Wisconsin studies, for example) through calibrating on one basin then using engineering judgment to transfer parameters to successive basins. Initial runs of the "transfer basins" have compared well with streamflow records, though further calibration could improve the comparison.

This technique of calibrating models where possible, then transferring information to other basins, has been used quite successfully. It is theoretically more acceptable than the empirical approaches frequently used where data are lacking because it makes maximum use of what data are available and because it uses those data in physically based, realistic calculations.

FINDINGS AND RECOMMENDATIONS

The significant findings and recommendations derived from the detailed evaluation of the Minnesota Model for Depressional Watersheds (MMDW), the Hydrologic Simulation Program Fortran Version (HSPF) and the Runoff Routing Model (RROUT) are as follows:

- o HSPF will require significant program modification before it can be loaded on the University of Minnesota CYBERNET 74 computer system (estimated cost is $15,000 to $20,000 in 1980 dollars).

- o RROUT will require some program modification to extend the length of the routing period in order to adequately route the snowmelt events. Presently, a 24-hour period is used. It is anticipated that a period of 96 to 120 hours would be appropriate (estimated cost is $5,000 to $10,000).

- o All three models simulate the accumulation and melt of the snowpack by means of the same algorithms. The data requirements for snow simulation are the same. The MMDW model has a slight variation from HSPF and RROUT in that it simulates frozen ground in an approximate way.

- o HSPF is a very comprehensive watershed model. It can be applied to a wide range of watershed problems including low flow, reservoir operation, in-stream water quality, and the buildup and washoff of pollutants from urban and agricultural areas. Only a small subset of the program's algorithms would be used to address the Red River of the North's flooding problems.

- All three programs appear to have no restrictions in applications to small (40- to 80-acre) drainage areas. HSPF and RROUT can readily be applied to the larger drainage basins of 500 square miles. MMDW, at the present, does not simulate the overland flow process which is important in the large basins.

- The research and modeling work presently being conducted by Dr. Parhek of North Dakota State University will be beneficial in the application of either the HSPF or the RROUT "LANDS" phase. As indicated in Chapter 2, the HSPX model that is being used in the Devils Lake Basin has the same "LANDS" phase as HSPF and RROUT.

- The excellent work conducted by Moore and Larson at the University of Minnesota (MMDW) has had very limited testing. During model development, it was applied to two watersheds in Minnesota with fairly good results. However, it is felt that the model needs more thorough testing before it is used in a major application.

- All three models evaluated utilize simplified kinematic wave methods for stream channel routing. These methods would not produce good results on the mainstem of the Red River of the North. Therefore, it is recommended that the watershed model be interfaced with a mainstem dynamic routing model. A program, developed by Dr. Daniel Fread of the National Weather Service Hydrologic Laboratory, is presently available. The program, entitled Dynamic Wave Operational Model (DWOPER), is already structured to accept tributary inflow hydrographs so the interfacing effort would be minimal. It is possible that the NWS River Forecasting Center in Minneapolis would be interested in having DWOPER operational as a flood forecasting tool. The possibility of a cooperative effort should be investigated.

Model Comparisons

A previous section of this chapter discussed which of the three models is best suited to the analysis of extremely small sub-basins (40-80 acres), and concluded that MMDW is unsuited due to lack of testing, while HSPF and RROUT are nearly equal with HSPF possibly having a slight advantage if used on a system with the half-word integer feature while RROUT has a distinct advantage on systems lacking that feature. This section will address which of the models is "best suited for analyzing Red River of the North type

basins that are under 500 square miles". The ensuing discussion acknowledges that the majority of Red River of the North type basins under 500 square miles are larger than the previously discussed 80 acres and require consideration of overland flow and channel routing.

Table 12 summarizes the features most critical to model application in moderately sized Red River of the North type basins. The MMDW model appears to be the least applicable of the three models since it has had only limited testing and no sensitivity analysis, requires significantly more detailed input data, lacks overland flow routing and is probably more costly to run. The main advantage of the MMDW model, its explicit treatment of depressional storage, does not overcome its other limitations.

HSPF and RROUT are very similar, differing primarily in three respects:

1. HSPF is a Fortran version of a more widely known model. Most experience has been with the previous version (HSP) which uses similar hydrologic algorithms, differing channel routing algorithms, and an entirely different computer language and structure. RROUT, though not as widely known, is also based on HSP. RROUT is also written in Fortran and uses essentially the same hydrologic and hydraulic algorithms as the original HSP.

2. HSPF is a more comprehensive model package, including not only hydrologic and hydraulic simulation features but also extensive data management facilities and water quality simulation components. RROUT is limited to hydrologic and hydraulic calculations.

3. HSPF routes the entire runoff hydrograph through the channel system, whereas RROUT performs channel routing only on the selected runoff events important to flooding analysis.

The selected routing performed by RROUT significantly reduces computer costs. Furthermore, RROUT's routing algorithms require less user calculation for channel characteristics and have been somewhat more extensively tested. Also, RROUT is compatible with a wider variety of computer systems. For these reasons, RROUT is recommended as the model best suited for hydrologic analysis of Red River of the North type basins of moderate size.

However, HSPF is also extremely well suited for such analysis, particularly if there is no need to mount the program package on the University of Minnesota Cybernet system. It

TABLE 12
EXPANDED MODEL COMPARISON MATRIX

Feature	HSPF	Model RROUT	MMDW
Computer Requirements			
Core Storage (bytes)	250K	200K	147K
Speed	moderate	fast	slow
Peripheral device needs	Disk	Disk & Tape	Disk
Computer Cost[1]	Medium	Low	High
Modification Cost[2]	$15,000-$20,000	$5,000-$10,000	?
System Limitations	Requires half-word integer function	standard	standard
Technical Considerations			
Snowmelt	good	good	good
Depressional Wetland algorithms	implicit	implicit	explicit
Depressional Wetland testing	extensive	extensive	none
Overland flow routing	Manning - Izzard	Manning - Izzard	none
Channel Routing[3]			
period	continuous	storms only	continuous
user input	extensive	moderate	minimal
theory	Kinematic wave	Kinematic wave	Kinematic wave
Reservoir Routing	storage	storage	none
Data Requirements			
Data handling modules	extensive	minimal	minimal
Additional data requirements[4]	moderate	moderate	high
Estimated data cost[4]	$16,000	$16,500	$37,000
User Consideratons			
Sensitivity Analysis Available	yes	yes	no
Reliability tested	extensive	extensive	limited
Documentation	complete	partial	partial
Availability			
source	U.S. EPA	CH2M HILL	U of MN
user fees	none	none	none

[1] Numerical estimates of computer costs are not comparable unless models are tested on similar computer systems with similar test basins. In lieu of such "benchmark" testing, relative costs are based on:
- HSPF is a large package, requiring a large, therefore, expensive, core storage. Also, HSPF runs channels continuously which is comparatively expensive.
- RROUT runs on a smaller, inexpensive system and routes only selected portions of the continuous runoff series.
- MMDW is extremely detailed, therefore, comparatively expensive.

[2] HSPF cost to eliminate half-word requirement. RROUT cost to expand channel routing period for analysis of larger basins. Estimates of MMDW modification costs are not possible since it is difficult to estimate the extent of modifications required to represent overland flow routing.

[3] This evaluation applies to routing in Red River of the North tributaries. As described elsewhere, none of the models are suited to channel routing in the Red River of the North itself.

[4] Refer to pages 3-42 through 3-47 for further explanation.

may in fact be desirable to take advantage of the comprehensive package inherent in HSPF while maintaining the cost savings inherent in the short-term routing approach of RROUT. This could be achieved by using HSPF for data handling and runoff calculation and applying the RROUT routing approach. The two models are compatible, requiring only moderate interfacing to enable RROUT to read from the HSPF data base (estimated cost $3,500). Alternatively, HSPF CHANNEL routing could be used in a discontinuous mode, routing only critical runoff events. The Southeastern Wisconsin Regional Planning Commission (SEWRPC) has used this approach with the earlier HSP versions with success (Walesh and Snyder, 1979). This approach would require considerably more user manipulation of channel input data, runoff files and CHANNEL run setups while using less well tested routing algorithms of HSPF.

HSPF is the only model studied which could be applied to Red River of the North type basins of moderate size without first undergoing some modification. If it were to be installed on a computer system without the half-word integer option, it too would require modification. Furthermore, HSPF might be more efficiently applied if it were modified for discontinuous runoff routing or interfaced with the channel routing section of RROUT.

RROUT appears to be a more cost efficient approach to analysis of Red River of the North subbasins. However, HSPF could also be applied to such analysis, albeit at a somewhat greater cost. A major factor in determining which of the two models should be used will be the persons or agencies actually commissioned to complete the modeling effort. The Stanford Watershed Model - RROUT approach is more straightforward to set up, whereas HSPF may be more readily applied by persons familiar with it. Neither model can be efficiently applied by a user lacking extensive experience in continuous hydrologic simulation of the depressional hydrology characteristic of the upper midwest.

CHAPTER 4
DATA BASE CONSIDERATIONS

This chapter identifies the specific data requirements of models derived from the Stanford Watershed Model, such as RROUT and HSPF. It discusses the adaptation of currently available data in the Rush River area for modeling purposes and identifies the additional data required for RROUT type analysis of the Rush River. Data needs, locations and collection modes are discussed for all data required for RROUT (or HSPF) simulation of the Rush River. This chapter outlines the general data types required for the model. It identifies the sources for existing data and recommends methods for collecting additional data. For many of the data sets discussed, it will be necessary to augment incomplete records from alternative existing data sources. The discussion suggests alternative sources for most data series, but does not attempt to provide a comprehensive guide to data series quality control. It discusses data accuracy and reliability only briefly.

ADEQUACY OF EXISTING DATA

This section presents the basic data categories pertinent to hydrologic modeling with the RROUT approach, i.e., using the Stanford Watershed Model to calculate runoff and RROUT for flow routing. For each data category, the reason the data are needed and the model use of these data are briefly presented. Available data in each category are evaluated and additional data needs are identified.

Hourly Precipitation

Precipitation data represent the initial water source which drives all other processes represented in the hydrologic model. The time interval of the precipitation data record must be small enough to enable accurate definition of the flood hydrograph, yet not so small as to require an uneconomical level of detail in calculation. Versions of the Stanford Watershed Model accept precipitation data in 5-, 15-, or 60-minute intervals. The 60-minute (hourly) data series is readily available from the U.S. Weather Bureau and is usually adequate for hydrologic analysis of large basins. However, for smaller basins (single fields or catchments, small tributary creeks, etc.), shorter time steps are often required. The 5- or 15-minute data are sometimes not available, but in these cases it is often acceptable to linearly distribute the hourly precipitation data into shorter intervals.

Analysis of the less frequent storms and associated flooding events require a precipitation data series covering a long

period of record. As indicated in Table 13, the probability of analyzing a 100-year storm from a study of a 50-year record is only 39 percent. U.S. Weather Bureau published and computerized records commonly begin in 1940 or later. However, earlier data are often available. It is desirable to use the longest available precipitation records for evaluation of the less frequent, larger events.

Spatial distribution of precipitation records are critical to accurate representation of storm events. Where thunderstorms produce critical runoff events, rain gage density of greater than one gage per ten square miles may be necessary for accurate representation of individual events. In most hydrologic simulation studies, however, individual thunderstorm events need not be precisely reproduced and less detailed data will suffice. In larger basins, such as the Rush River, frontal systems and spring thaws produce more critical runoff than thunderstorms, and these may be adequately represented with a precipitation network density of less than one gage per one hundred square miles.

The location of hourly precipitation data stations (Figure 12) indicates that the data for Fargo, North Dakota, best represents most of the Rush River basin. However, data from the other nearby stations should be used to augment, verify and fill in missing periods of the Fargo record. The Fargo record extends from 1930 to the present, providing an adequate period of record for runoff simulation and frequency analysis.

The available network of hourly precipitation data is not as dense as desired for hydrologic simulation of the Rush River. However, the data may be supplemented by that from daily precipitation gages. It would also be useful to collect hourly precipitation data near Amenia to improve the rainfall characterization during the calibration period.

Daily Precipitation

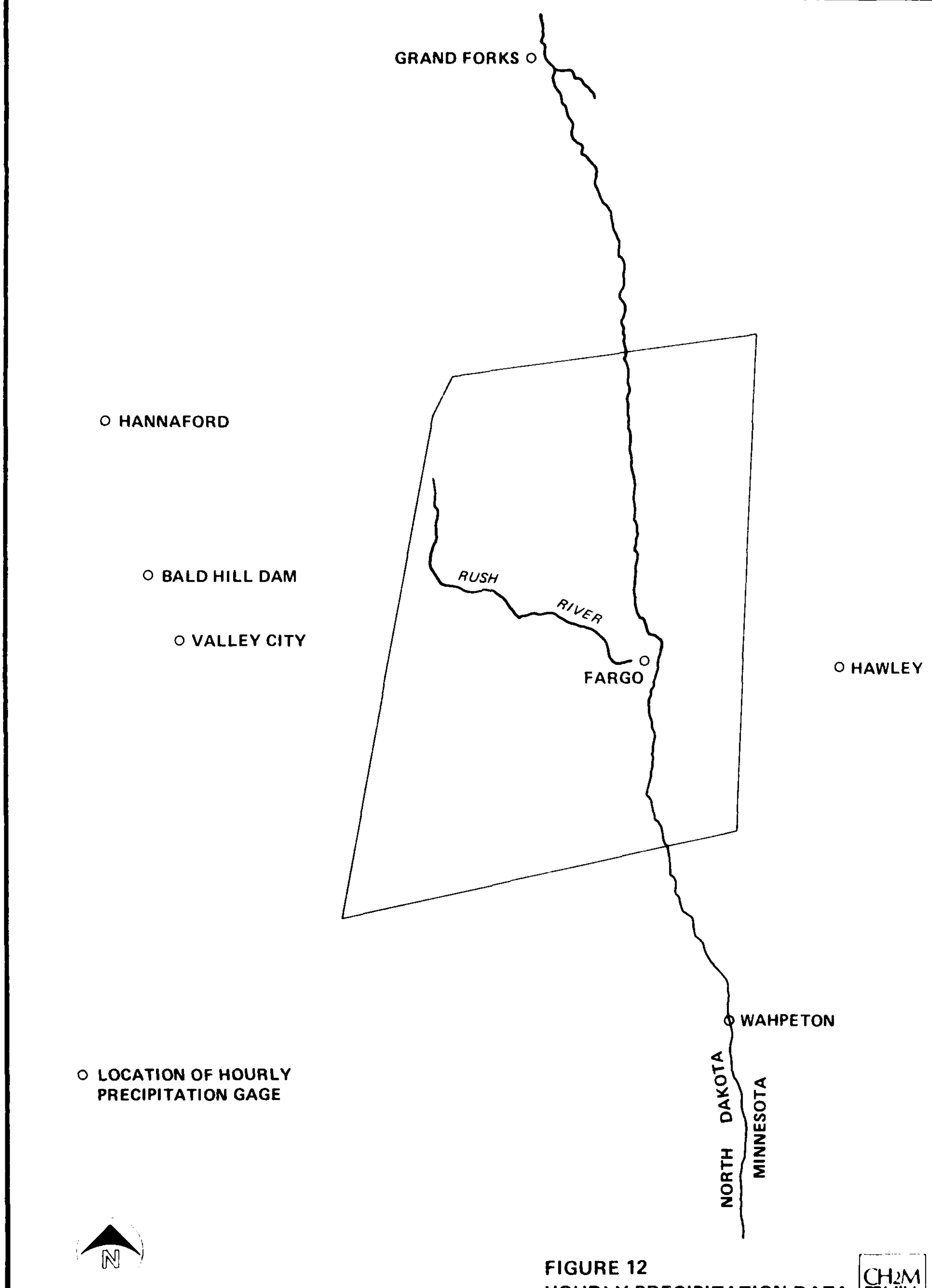
Daily precipitation data are used primarily to supplement the hourly precipitation data previously discussed. Locations at which daily precipitation data are available near the Rush River watershed are indicated in Figure 13. Data obtained from these stations can be distributed into an hourly format through comparison with the hourly data for the nearby hourly station. For example, the daily data at Colgate could be distributed through comparison with the Valley City hourly record. Using the hourly data files thus created, one can achieve a reasonable representation of the precipitation falling on the Rush River basin.

Table 13

PERIOD OF RECORD EFFECT*

Period of Record	Probability that the 100-year Event Occurs in the Period
10	9.6
25	22.2
50	39.5
75	52.9
100	63.4
200	86.6
300	95.1
500	99.3

* Calculated from Bruce and Clark, 1966, p. 151.



SCALE: 1" = APPROXIMATELY 16 MILES

FIGURE 12
HOURLY PRECIPITATION DATA
RUSH RIVER, NORTH DAKOTA

CH2M HILL

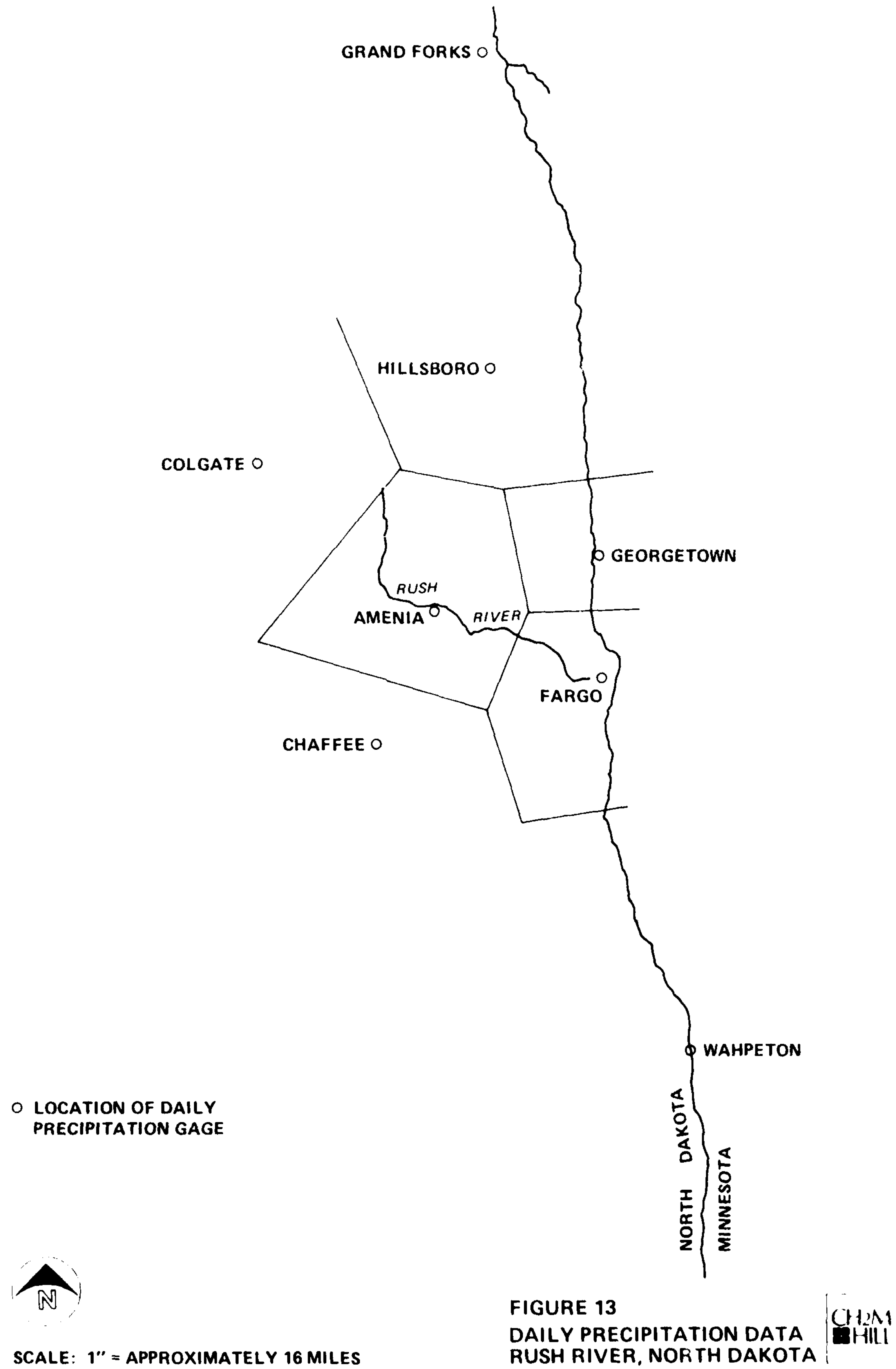


FIGURE 13
DAILY PRECIPITATION DATA
RUSH RIVER, NORTH DAKOTA

Snow

Since the hydrologic model calculates snow accumulation and snowmelt, it does not require snow data as input. However, any available data on snow cover and snow depth can be extremely useful in calibrating the snow algorithms of the hydrologic model. Such data are usually available from first order U.S. Weather Bureau stations such as Fargo, North Dakota. Snow data are also available from the Corps of Engineers in St. Paul, Minnesota. The snow data available in the Rush River area are more extensive than that often available in hydrologic simulation studies and could be considered adequate.

Temperature

Temperature data are used by the hydrologic model to determine when precipitation falls as snow, and also in the snowmelt algorithms. Temperature data are available in the form of maximum and minimum daily temperatures recorded by the National Weather Service. Such data are available at Amenia, Colgate, Grand Forks, Fargo, Wahpeton, and Georgetown.

Dew Point

Dew point temperature data are used in the algorithms which calculate snowmelt. Such data are available from the National Weather Service on a daily basis for Fargo, North Dakota.

Wind

Wind data are also used in the calculation of snowmelt. Wind data are available at Fargo, North Dakota, on a daily basis from the National Weather Service.

Sunshine

Sunshine data are not used specifically by the recommended hydrologic model. However, percent possible sunshine or cloud cover data can be used to calculate the solar radiation data. Percent possible sunshine data are available from the National Weather Service at Fargo, North Dakota.

Solar Radiation

Radiation data are necessary to the calculation of snowmelt. The nearest National Weather Service station to the Rush River basin which records radiation data is the station at Bismarck, North Dakota. However, since radiation does not vary significantly over a relatively large area, the data from Bismarck should be sufficient for use in the Rush River simulation.

Evaporation

The hydrologic model utilizes evaporation data to estimate moisture losses to evapotranspiration. Daily evaporation data are available from the National Weather Service for Fargo, North Dakota, for the period 1970 to present. However, evaporation data are usually only measured during the summer months. For other months, and for periods prior to 1970, evaporation data may be estimated from data for temperature, dew point, wind, and radiation.

Streamflow

Like snow data, streamflow records are used only in the calibration of the hydrologic model. Streamflow is not a necessary input to such hydrologic modeling. However, the accuracy of the hydrologic model can only be tested against measured streamflow. Streamflow data are available for the Rush River at Amenia, North Dakota. The data are available on a daily basis from 1946 to present. These data could be considered adequate for the calibration of the hydrologic model to the Upper Rush River watershed. However, it would be highly desirable to have additional streamflow data available at areas characterizing unique hydrologic situations. Particularly, it would be desirable to have data available which represent outflow from a watershed composed almost entirely of depressional storage. These data would be used to calibrate the land segments which would be later used to simulate all of the depressional storage areas within the basin. Additional streamflow data would also be desirable near the mouth of the Rush River to enable calibration of the lower part of the basin.

Topography

Topographic data are used by the model for two primary purposes. First, topographic data are used to define the watershed boundaries and, hence, the areas tributary to each reach of the watershed model. Secondly, topographic data are used to define the average land surface slope which defines the overland flow runoff velocity. Adequate topographic data are available from the U.S. Geological Survey, 7.5-minute quadrangle topographic maps. Additional topographic data are available from the U.S. Soil Conservation soil surveys.

Land Use and Cover

Land use and land cover data are essential to the definition of the hydrologic regime of any watershed. Land use data and vegetative cover data are used to determine percent impervious of a watershed, as well as the amount of area subject to high interception rates from vegetation. Infor-

mation regarding land use and vegetation in the Rush River watershed is available from several sources, including LANDSAT and U-2 photos available from the EROS Data Center, the U.S. Forest Service Statewide Woodland Inventory, and the North Dakota Geological Survey land use inventory.

Soils

Soils characteristics are very important in hydrologic cycles in that tight soils can prevent infiltration and loose soil can encourage infiltration. Soils data are input to the hydrologic model as infiltration capacity factors and soil moisture factors. Information useful in calibrating these factors can be acquired from the U.S. Soil Conservation Service Soil Surveys for Cass and Traill Counties. At present, the Cass County Soil Survey is unpublished. However, it is expected to be published in 1981 or 1982. Prior to that publication date, it will probably be possible to obtain the necessary data directly from the U.S. Soil Conservation Service.

Stream Data

The hydraulic routing model is primarily concerned with the stream and drainage systems. These stream systems must be designated to the model in terms of the hydraulically important characteristics, i.e., reach length, channel slope, channel cross section, and channel roughness. Stream length, slope and network can be defined from USGS topographic maps. Channel roughness and cross section data are currently available from the U.S. Army Corps of Engineers for the Lower Branch of the Rush River basin, only.

ADDITIONAL DATA REQUIREMENTS

The previous section briefly identified the data readily available for hydrologic simulation of the Rush River basin. This section discusses required data which are not readily available but which should be collected prior to hydrologic simulation. The data needs and suggested collection procedure are predicated on current understanding of the purpose, time frame, objectives and prospective budget of the hydrologic analysis. Obviously, more thorough and detailed data could be recommended if the object were to develop a hydrologic model as a research tool and less data collection has historically sufficed for flood prediction or design studies where a large factor of safety was inherent in the analysis. The following recommendation represents a balance between the theoretically desired complete data base and limited time and budget associated with engineering planning and analysis studies.

Streamflow

The hydrologic model could be calibrated to the available streamflow at Amenia. However, since a major purpose of the modeling effort is to demonstrate the effect of depression storage areas and their drainage, it is desirable to collect additional streamflow data representing a uniform basin displaying the characteristics of depression storage. The hydrologic model could then be calibrated to these data to ensure accurate representation of the depression storage segments in the Rush River model.

The basin selected for depression storage flow monitoring should be as large as possible without seriously compromising the criteria that it be uniformly representative of undrained (i.e., no agricultural drainage, etc.) depressional topography. The basin should in all other respects be similar to the larger Rush River watershed. The basin need not necessarily lie within the Rush River watershed, but it should be near enough to experience similar meteorologic conditions. Perhaps a suitable basin in the Marsh Creek area could be identified.

Outflow from the basin should be continuously recorded for as long a period as possible. A minimum of one complete seasonal cycle (1 year) is suggested. (Calibration could begin before the data were all compiled.) Outflow should be monitored with reasonably accurate equipment (±10 percent is the USGS criteria for good flow monitoring data). The specific equipment must be selected to fit the particular requirements of the outflow point of the basin selected. The apparatus must include a control section (broad crested wier, Parshall flume, natural constriction, uniform channel, etc.) which is unaffected by backwater, and a stage recording device. If the control is a natural, uncalibrated stream section, several detailed velocity profiles will have to be measured under a variety of flow regimes to define the stage-discharge relationship.

Further accuracy in defining the effect of draining or urbanizing depression storage areas could be achieved if drained and urbanized basins near the depressional area were also monitored. However, previous experience with modeling such areas, the available understanding of their hydrologic effects, and the available data at Amenia, should combine to enable accurate representation of such areas even without data collection from such specifically defined areas.

The data available at Amenia only allow for calibration of the upper portion of the Rush River basin. Streamflow data should be collected nearer the mouth of the watershed in order to verify the hydrologic representation of the lower basin.

Stream Data

Data defining the stream channels and major drainageways must be collected. Those data available from the U.S. Army Corps of Engineers may be used to describe the Lower Branch of the Rush River. Since the modeling effort presently envisioned will not involve detailed calculation of backwater profiles, extremely accurate definition of stream sections, flood plains and structures are not required. However, typical stream sections must be surveyed to a degree which provides data sufficient to define the normal depth-area characteristics of each stream reach.

USGS topographic maps, aerial photographs and other available planimetric views of the basin should be inspected. Stream segments which are probably fairly uniform should be identified, as should those road crossings or other constrictions which may, under high flow, cause significant upstream retention. The planimetric inspection should be augmented by field verification as necessary. Usually a windshield survey is sufficient.

Cross sections typical of each of the identified stream segments should be measured. About two sections will probably be required for each five miles of stream in rural areas, more will be required in more developed areas. Stream cross sections should include both the channel and the floodplain. Survey accuracy to the nearest ±0.1 feet is more than adequate. For the larger channels, ±1.0 feet would suffice. Photos should be taken at each section to allow definition of the Manning roughness coefficients. The section data should include all major breakpoints, including right and left bank toe and top and enough data to define the flood plain shape.

Each possible constriction should be inspected by a hydraulic engineer and, if it indeed appears to represent a constriction, sufficient data should be collected to define its hydraulics as an outflow as well as the depth-area nature of the upstream retention area. The latter data set may be available from the topographic maps.

The entire basin and most stream reaches should be visually inspected by the persons developing the hydrologic and hydraulic models to ensure familiarity and enable reasonable judgments regarding data reliability and required assumptions.

Precipitation Data

Additional hourly precipitation data would be desirable during the detailed calibration period (i.e., that period covered by the specially collected streamflow data). Such data would improve the representation of individual storms

which may affect different parts of the basin in different ways. Installation of recording rain gages near Amenia and near the depression storage flow monitoring basin would provide data to improve calibration. However, it is believed that adequate calibration could be achieved if these data were lacking.

DATA COMPILATION

Whatever the source of a particular data item, it will be necessary to translate the data provided from the original source into a form compatible with the computer model. The watershed model and RROUT user's instructions provide detailed descriptions of the required formats. The following section briefly presents data manipulations, consistency checks and quality controls which may increase efficiency, reduce frustration and generally prove useful in the final preparation of the data.

Hourly Precipitation

The hourly precipitation data are available from:

> National Climatic Center
> Federal Building
> Ashville, North Carolina
> 704/258-2850

Data since 1948 are generally available on magnetic tape, cards and/or hard copy. Prior to that year, most data are avialable only on hard copy. Meteorologic data for an entire state may often be obtained for little additional cost over that required for data from a few stations. If this is the case, data for the entire state should be obtained to provide a broader base of backup data and so it will be available when and if it becomes desirable to simulate the remainder of the Red River of the North basin.

When obtaining data from the National Climatic Data Center, it is also wise to request copies of the station histories for data stations of primary interest. These are useful in determining reasons for changes in record, instrument height, observation times and other necessary information mentioned in later sections of this discussion.

Data obtained on magnetic tape must be reformatted, probably through a user generated computer program, for input to the hydrologic model. Hard copy data must be keypunched. All keypunching should be manually checked to ensure accuracy--one misplaced decimal point can be disastrous when it leads to using a 10 inch per hour rainfall rather than 1.0 inch per hour in a runoff calculation.

National Weather Service data include symbols for missing data, trace amounts of rainfall and cases where hourly values were accumulated and reported as a lump sum at the end of an extended period. The computer models generally do not interpret these symbols. Prior to using the data, it is necessary to inspect the data files, identify the symbols and, through comparison with other nearby gages, translate the symbols into hourly precipitation values. A record of all such data interpretation, noting station and hours where the interpretation was required and the assumptions made in providing the data (e.g., used data from station B, etc.), should be maintained.

Data obtained from special gages suggested previously would require coding, data gap filling and keypunching prior to computer input.

Consistency of all the available precipitation records should be checked through double mass analysis (Bruce and Clark, 1966, p. 160 or other hydrology texts). If records are not consistent, the reason for inconsistency should be identified. The station histories will be useful in this review. After the cause of the variation is identified, it may be possible to logically adjust the inconsistent data to provide a more realistic representation of actual, long-term precipitation.

Daily Precipitation

Daily precipitation data are available from the same source in essentially the same forms as hourly precipitation data. They too must be keypunched or reformatted, have data gap symbols interpreted and have inconsistencies identified and corrected where possible.

Several algorithms and programs are currently in use for distributing daily data into hourly or shorter time intervals. The simplest of these merely distributes the daily rainfall evenly over the entire day. However, a far more realistic representation is achieved if daily records are distributed according to patterns recorded at nearby hourly stations. In distributing daily records, it is essential to note the observation times at the various stations and ensure that all distributions are based on the same definition of a day (i.e., from midnight to midnight, 7 a.m. to 7 a.m., or noon to noon).

Snow

Snow data are available in the National Climatic Center climatological data series as well as from the St. Paul District, U.S. Army Corps of Engineers. Data from the latter source should be scrutinized to determine initial

estimates for model snow parameters such as depth of snow at which 100 percent aerial coverage is achieved, etc. Efforts should be made to assure that the Corps of Engineers' snow surveys include the Rush River basin during the period of streamflow data collection. Data from the National Climatic Center should be reviewed to determine temperature below which precipitation usually falls as snow, normal snow density, etc. These data will also be used in calibration by comparing model predicted snowfall and pack depth with the records.

Temperature

Air temperature data, recorded as maximum and minimum daily temperatures, are available from the same source in essentially the same forms as hourly precipitation. They must be keypunched or reformatted and data symbols must be interpreted.

Dew Point

Dew point data are available from the same source in essentially the same form as hourly precipitation. They must be keypunched and reformatted and data symbols must be interpreted. Another nearby record from which missing data can be inserted in the Fargo, North Dakota, data series is not available. Missing data may be estimated from the preceding day's record, from Grand Forks, or, for extended periods, it may be possible to develop a relationship between dew point and air temperature.

Wind

Wind data are available from the same source in essentially the same forms as hourly precipitation.

Wind data are recorded at differing heights above ground surface. For purposes of hydrologic modeling, the data should be converted to a uniform height of two feet above ground surface. The following empirical relationship can be used for the conversion:

$$\frac{U_1}{U_2} = \left(\frac{H_1}{H_2}\right)^{1/7}$$

where U_1 and U_2 = wind movement at heights H_1 and H_2, respectively (Linsley, 1975).

It is important to note that wind data are often recorded in a variety of units (average miles per hour, knots, etc.). Care should be taken in converting to the units required by the model, i.e., miles per day.

Sunshine

Sunshine data are available from the same source in essentially the same format as hourly precipitation data. Where sunshine data are lacking, percent of cloud cover data can often be used. Since sunshine and/or cloud cover are fairly constant over large areas, data can be transferred from relatively distant stations for use in the Rush River simulation if necessary.

Solar Radiation

Existing solar radiation data are available from the same source in essentially the same format as hourly precipitation data. Missing data may be estimated from sunshine or cloud cover data in accordance with the method proposed by Homer, Weiss, and Wilson (1954).

Evaporation

Evaporation data are available from the same source in essentially the same format as hourly precipitation data. For periods of missing data, evaporation can be estimated from temperature, dew point, wind and radiation data through the techniques described by Kohler, Nordenson and Fox (1955).

Most available evaporation data are in the form of pan evaporation. For hydrologic model use, this should be converted to lake evaporation rates. Conversion factors have been developed for many areas of the country--the local weather bureau office and nearby universities should be contacted for information regarding such factors.

Streamflow

Daily streamflow data at Amenia are available from the U.S. Geological Survey (USGS) in published form and on computer tapes. If only the published data are obtained, they must be keypunched if computer plotting or statistical techniques are to be used in calibration. If the tapes are obtained, it will probably be most efficient to obtain the data for the entire state at one time. Data not used in simulating the Rush River may be used in later studies of other portions of the Red River of the North.

Daily streamflow data are suitable for calibration of the hydrologic budget portion of the model. The full model calibration, including flood routing, will require more detailed data for selected storms. Such data, in the form of stage record plc s and related stage discharge data, are available from state USGS offices on special request. Several representative storms during the calibration period

should be identified as early as possible in the data gathering process so that the USGS office may have sufficient lead time to fulfill the special data request.

Streamflow data at other locations will be available from the data collection activities previously recommended. Special arrangements may have to be made with the USGS to assure that Amenia records for the period covered by the specially collected data are available in a timely manner--publication may take more than a year.

Complete information (history, description, etc.) should be obtained for each gaging station. During calibration, it will be necessary to evaluate the accuracy of the recorded data as well as that of the model prediction.

Topography, Land Use and Soils

These data may be obtained from the USGS topographic maps, North Dakota Geological Survey maps, LANDSAT photos, U.S. Forest Service woodland inventories and the SCS soil surveys. Reduction of these data for model input requires more judgment than mathematical manipulation. The reader is referred to the Stanford Watershed Model input parameter descriptions for a discussion of how the data will be entered in the model. Past experience with using similar data sources to derive model input parameters simplifies the process, hence the reader is referred to calibration reports for application of the Stanford Watershed Model or its derivatives (HSP, Kentucky Watershed Model, etc.) for further information regarding data reduction methods.

Stream Data

Stream length and slope may be measured directly from topographic maps. Stream section parameters and their derivation from the field data collection efforts are thoroughly described in the UROS04 manual (Lumb, 1975). It is usually helpful to plot the stream section and measure the parameters from the plot. Alternatively, it is often possible to develop the parameters through programs designed to reduce field data for input to the Corps of Engineers' program, HEC-2.

The Manning's roughness coefficient (n) is the only stream parameter which cannot be measured in a fairly straightforward manner. However, several references are available to guide in the selection of the proper roughness coefficients. Two of the more complete references are Barnes, 1967, and Fasken, 1963.

ADDITIONAL CONSIDERATIONS

A large quantity of data is required for the RROUT approach to simulation of the Rush River drainage basin. Most of the required data are readily available in computer readable form. Considerations in reducing these data to forms acceptable to the models are presented in earlier sections.

It is recommended that a minimum of one year's continuous streamflow data be collected from a basin typical of the depression storage topography, and perhaps from an already drained depressional area. Streamflow data for that same period should also be collected near the mouth of the Rush River. Collection of hourly precipitation data for that period near Amenia and near the depression storage basin would be useful. Detailed field investigations of stream and drainageway characteristics are recommended throughout the basin.

A significant portion of the effort of preparing data for hydrologic studies is expended in data reduction and verification. This effort can be greatly expedited through the use of experienced personnel and previously developed utility programs designed to reduce data for the models to be used.

Much has been said about the fact that hydrologic simulation cannot be more accurate than the data used as input. It must also be acknowledged that a calibrated hydrologic model should not be expected to be more accurate than the calibration data. Thus, if the Rush River model is to be calibrated to USGS streamflow data at Amenia which is judged to be within 10 percent of true flow[3], it is unreasonable to strive for much greater than 90 percent agreement between calibrated and recorded flows.

In order to assure maximum reliability of the hydrologic model it will be necessary to establish careful quality control on all aspects of data collection, data reduction and model operation. A formal program of quality control, including spot checks, cross checks and reasonableness tests should be instituted regarding each step of the data handling procedure.

[3]Amenia records are evaluated as good (USGS, 1979, p. 115). Good records are defined as within 10 percent (Ibid, p. 24).

CHAPTER 5
SUMMARY AND CONCLUSIONS

The increasing flood damages in the Red River of the North basin prompted investigations into the probable causes of the apparent increase in flood severity. It has been postulated that the increase in flood flows may be related to the recently common practice of installing agricultural drain tiles and ditches to increase the tillable acreage in depressional and wetland areas. This study was undertaken to evaluate presently available hydrologic models and determine which of them would be best suited to the analysis of the causes of increased Red River of the North flooding.

Initial investigations concluded that any model suitable for such analysis would have the following characteristics:

1. ability to simulate the runoff due to snowmelt and rain with snowmelt;

2. ability to simulate the wetland and depression storage effects;

3. ability to simulate the effects of surface drainage projects;

4. ability to accurately route flows in the tributaries and the mainstem of the Red River of the North under dynamic flow conditions;

5. contain model algorithms based upon proven hydrologic and hydraulic principles and well tested in terms of previous applications;

6. be readily available and have data base requirements which are not excessive;

7. incorporate a continuous moisture balance so that assumptions do not have to be made regarding antecedent soil moisture prior to running a hypothetical storm;

8. ability to simulate runoff from both small and large drainage areas; and

9. ability to produce runoff events and analyze alternatives at a reasonable cost.

Of thirty-six models originally investigated, only thirteen were found to have the majority of these characteristics. Each of these thirteen models, listed and evaluated in Table 1, were researched in greater depth and their salient characteristics described in Appendix C. The investigation

concluded that three models, the Hydrocomp Simulation Program Fortran version (HSPF), the Runoff and Routing model (RROUT) and the Minnesota Model for Depresssional Storage (MMDW) hold the greatest promise for fulfilling the Red River of the North modeling requirements. However, none of these models is suited to analysis of the hydraulics of the Red River of the North itself. It is recommended that a detailed hydraulic model utilize input from the selected subbasin models and route flows in the mainstem separately. The three subbasin models are described in detail in Chapter 3. Their ability to analyze depressional and wetland hydrology, their adaptability to large and small subwatersheds in the Red River of the North basin, and their respective data requirements were investigated and compared. It was concluded that, although MMDW includes the most direct analysis of depression storage, its extensive data requirements and extremely limited application history reduce its utility for analysis of the Red River of the North problems. RROUT and HSPF are very similar to one another, and either could be applied to analysis of flooding in tributaries of the Red River of the North. RROUT's selective storm routing and analysis is more cost-effective than HSPF's analysis of all events, and hence RROUT is perferred for the proposed modeling study. However, since model utility is significantly affected by user experience, the final selection of the model to be used should proceed only after the model application team has been identified.

Chapter 4 presumes that either HSPF or RROUT will be chosen for the modeling of the Red River of the North subbasins and discusses the data requirements for such a modeling effort to be initiated in the Rush River subwatershed. Most required data are already available from secondary sources. Only calibration data, detailed streamflow records, and basin specific precipitation data and stream channel data need be field collected. Guidelines for collecting the necessary data and for data reduction prior to model input are presented.

Hydrologic models capable of analyzing the increasing flood hazards of the Red River of the North drainage basin have been identified. Data required for their use are largely available, particularly in the Rush River subbasin. Some additional data, particularly calibration data and stream channel data, must be collected if modeling studies are to be accomplished. Such data would enable more rigorous definition of the hydrologic regime of the Red River of the North and would be necessary to any study of the relationship between man's activities and increased flooding in the basin. It is recommended that collection of such data commence as soon as practical. The detailed design of the data collection program should be directed by persons familiar with hydrologic modeling, as well as conventional hydrologic techniques, to assure maximum future utility of the data collected.

Application of hydrologic modeling techniques to the investigation of Red River of the North flooding is a feasible analysis tool which could greatly enhance understanding of the causes of increased flood damages, while providing a tool for the analysis of the effects of flood mitigation measures. Once set up and calibrated, such models would also prove useful in selecting and evaluating proposed flood damage reduction measures. However, experience has repeatedly demonstrated that model utility is highly correlated to the experience and knowledge of those applying the models. It is recommended that sophisticated hydrologic modeling studies only be undertaken under the direction of persons experienced in similar application of equally complex models.

APPENDIX A
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APPENDIX B
HYDROLOGIC/HYDRAULIC MODELS CONSIDERED

Acronym	Model	Source
CRSM	Chicago Runoff Simulation Model	City of Chicago Bureau of Engineering
SWMM	Storm Water Management Model	U.S. EPA
HSP	HYDROCOMP Simulation Program	HYDROCOMP, Inc.
STORM	Storage, Treatment, Overflow, Runoff Model	U.S. Army Corps of Engineers Hydrologic Engineering Cente
SAM	System Analysis Model	CH2M HILL, INC.
ILLUDAS	Illinois Urban Drainage Area Simulation	Illinois State Water Survey
MITCAT	MIT Catchment Model	Resource Analysis, Inc.
UROS	Urban Runoff Simulation	Georgia Institute of Technology
UCUR	University of Cincinnati Urban Runoff Model	University of Cincinnati
NERO	Chicago Hydrograph Method Runoff Computations	City of Chicago Bureau of Engineering
HYDRA	Dynamic Model for Urban Hydrologic Systems	University of Nebraska-Lincoln
ANALOG	Analog Computer Simulation of the Runoff Characteristics of an Urban Watershed	Utah Water Research Laboratory, Utah State University
RRL	Road Research Laboratory Model	British Road Research Laboratory
RROUT	Runoff and Routing Model	CH2M HILL, INC.
CSSR	Computer Simulation of Stormwater Runoff	Northwestern University
MRM	Modified Rational Method for Estimating Storm Runoff from Urbanizing Areas	Harvard University

SWM IV	Stanford Watershed Model, Version IV	Stanford University
KWM	Kentucky Watershed Model	University of Kentucky
TWM	Texas Watershed Model	University of Texas at Austin
NWSRFS	National Weather Service River Forecast System	National Weather Service Office of Hydrology
GTWS	Georgia Tech Watershed Simulation	Georgia Institute of Technology
SSARR	Streamflow Synthesis and Reservoir Regulation Model	U.S. Army Corps of Engineers, North Pacific Division
HEC-1	HEC-1 Flood Hydrograph Package	U.S. Army Corps of Engineers, Hydrologic Engineering Center
USGSRR	U.S. Geological Survey Rainfall Runoff Model	U.S. Geological Survey Water Resources Division
HYMO	Problem-Oriented Computer Language for Hydrologic Modeling	U.S. Department of Agriculture Research Service
TR-20	Computer Program for Project Formulation Hydrology	U.S. Department of Agriculture Soil Conservation Service
MMDW	Minnesota Model for Depressional Watersheds	University of Minnesota Department of Agricultural Engineering
HSPF	Hydrologic Simulation Program Fortran Version	U.S. Department of Environmental Protection and HYDROCOMP
USDAHL-77	Model of Watershed Hydrology	U.S. Department of Agriculture Hydrographic Laboratory
3-TUBE	Three-Tube Flood Routing Program	U.S. Department of Agriculture Hydrographic Laboratory
DFRM	Dynamic Flood Routing Model	U.S. Army Corps of Engineers, Missouri River Division

URBDRAIN	Urban Storm Drainage System Model	Purdue University
BATTELLE	Battelle Urban Wastewater Management Model	Battelle Pacific Northwest Laboratories
DORSCH	Dorsch Consult Hydrograph Volume Method	Dorsch Consultants
SOGREAH	Sogreah Looped Sewer Model	Sogreah Consultants
DLBM	Devils Lake Basin Model	HYDROCOMP/North Dakota State University

APPENDIX C
MODEL EVALUATION FORMS

1. Model name:

2. Model availability:

   a. Available for general usage?

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?

3. Computer requirements:

   a. What programming language was used?

   b. Computer system used for model development?

   c. Is program readily adaptable to major computer systems other than the one indicated above?

4. Data base requirements:

   a. Is model continuous or event?

   b. Briefly describe data input requirements.

5. Model applications:

   a. Was model developed for a particular study area and, if so, which area?

   b. Are calibration results available for any past applications?

   c. Does the model have the demonstrated capability of reproducing historic flow events?

   d. Can the model be used to simulate flows that might occur under future land use conditions?

6. Basic model theory and methodologies:

   a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

   b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

10. Can the model route flows in both open channels and pipes or neither?

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

12. Briefly discuss any <u>unique</u> features of the model that are not covered in any of the above questions.

13. Provide any data you can readily obtain on costs for running this model.

1. Model name: USGSRR

2. Model availability:

   a. Available for general usage? Yes, order from USGS

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?

3. Computer requirements:

   a. What programming language was used?

      Fortran IV

   b. Computer system used for model development?

      CDC/IBM

   c. Is program readily adaptable to major computer systems other than the one indicated above?

      Yes

4. Data base requirements:

   a. Is model continuous or event?

      Continuous

   b. Briefly describe data input requirements.

      Rainfall and evaporation data
      Streamflow - observed for calibration
      Soil moisture and infiltration parameters (7) - two-layer soil, Philip's infiltration, evapotranspiration from both layers
      Impervious area - impervious retention (depression storage)
      Routing data - kinematic wave with finite difference solution for overland flow and channel
      - modified-Puls reservoir

5. Model applications:

   a. Was model developed for a particular study area and if so which area?

      No

   b. Are calibration results <u>available</u> for any past applications?

      Yes

   c. Does the model have the demonstrated capability of reproducing historic flow events?

      Yes

   d. Can the model be used to simulate flows that might occur under future land use conditions?

      Yes

6. Basic model theory and methodologies:

   a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

      <u>Runoff</u>: Soil moisture is simulated using a two-layer soil; base moisture storage (BMS) and an upper zone saturated moisture storage (SMS). Infiltration is done by Philip's equation. Irrigation can be simulated. ET occurs from SMS then BMS. No interflow or base flow components.

      Effective impervious areas have a retention abstraction; noneffective impervious areas have their rainfall added to pervious areas.

      <u>Routing</u>: Four segments considered - overland flow, channel, reservoir, and nodal channel - can receive flow from 3 other segments and 4 overland flow segments; kinematic wave routing used, including pipe flow. Reservoir routing can be done by linear storage, i.e., outflow is a linear relation to storage or by a modified Puls routing.

      Nodal segments - junction to combine segments or can be used to input user defined hydrograph.

b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

Implicitly - use soil moisture relationship for marsh area with reservoir routing to account for storage.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

No

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

Yes

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

Implicitly - vary soil moisture parameters for lower soil zone - model does not have groundwater component, so it would not be as good as HSP.

10. Can the model route flows in both open channels and pipes or neither?

Both

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

Yes - 3 rain gages

12. Briefly discuss any <u>unique</u> features of the model that are not covered in any of the above questions.

The model uses a 24-hour time step between events to account for soil moisture and from 1 minute to 15 minute time steps during events. Model is limited to 50 segments, no more than 6 consecutive days with rain and 60 events per run For long-term simulations - would need to make several runs.

Optimization on runoff volumes using Rosenbrock's methodology can be used to calibrate model.

Model designed for smaller, urban watersheds. Using it for Red River of the North would be pushing its intended capabilities.

AD-A135 697 ANALYSIS OF EXISTING HYDROLOGIC MODELS RED RIVER OF THE NORTH DRAINAGE BASIN NORTH DAKOTA AND MINNESOTA(U) CH2M HILL MILWAUKEE WI NOV 80 DACW37-79-C-0817 2/2

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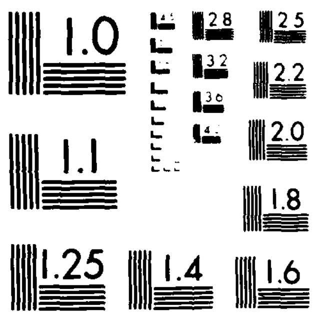

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

13. Provide any data you can readily obtain on costs for running this model.

CDC - 1340 time steps took 12 seconds execution for 19 segments.

Cost depends on length of storms (time steps), but appears to be quite reasonable for a continuous model.

1. Model name: HSPF

2. Model availability:

   a. Available for general usage? Yes - From EPA in early 1980. A workshop attendance required.

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?

3. Computer requirements:

   a. What programming language was used?

      Fortran IV

   b. Computer system used for model development?

      Honeywell

   c. Is program readily adaptable to major computer systems other than the one indicated above?

      Will run on IBM. Will require modification prior to loading on a CDC, DEC or Univac.

4. Data base requirements:

   a. Is model continuous or event? Continuous

   b. Briefly describe data input requirements.

      Hourly precipitation, daily evapotranspiration potential, daily radiation and max-min temperature; parameters to describe the watershed segment characteristics; parameters to describe the stream channel cross sectional properties including the floodplain and roughness coefficients.

5. Model applications:

   a. Was model developed for a particular study area and, if so, which area?

      No, intent was to maintain generality.

   b. Are calibration results <u>available</u> for any past applications?

      Yes

c. Does the model have the demonstrated capability of reproducing historic flow events?

Yes

d. Can the model be used to simulate flows that might occur under future land use conditions?

Yes

6. Basic model theory and methodologies:

a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

Simulates the following processes:

Interception - an initial abstraction from precipitation limited to a preset maximum value. Impervious Area - a preset percentage of precipitation diverted directly to runoff representing rainfall on streams, lakes and impervious surfaces that are hydraulically connected to the channel system. Infiltration - a variable function of soil moisture as derived through calibration. Based upon Philip's equation. Overland flow - equations based on turbulent flow and fitted to experimental data. Soil Moisture - lower zone storage filled by infiltration and percolation from upper zone storages. Depleted by evapotranspiration at a rate dependent on the water in storage. Snowmelt - based upon simulating continuous heat exchange between the snowpack and the atmosphere. Considers radiation, convection, condensation, rainfall and ground melt. Channel Routing - based on a kinematic wave approach that uses the actual dimensions and roughness coefficients of the physical system. Can simulate reservoirs, lakes and diversions.

b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

Implicitly by means of the upper zone storage function which simulates the depressional storage that doesn't contribute directly to runoff.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

Yes, has good snowpack and snowmelt algorithms.

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

   Yes, can be treated as part of a specified drainage network.

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

   Implicitly by using the interflow parameter. Would require some calibration adjustment and would be an approximation at best.

10. Can the model route flows in both open channels and pipes or neither?

    Open channel and pipes

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

    Yes

12. Briefly discuss any <u>unique</u> features of the model that are not covered in any of the above questions.

    Simulates the complete hydrologic cycle and maintains a water balance. Can accurately simulate peak flows and low flows.

13. Provide any data you can readily obtain on costs for running this model.

    Costs vary widely depending on the computer system and priority that is used. An average estimate for computing the land surface runoff with snowmelt is $4.00 per segment per year. Thus, 3 segment types for 25 years would cost $300.00. Channel routing costs approximately $1.00 per reach per year.

    Costs are relatively high, but results obtained have usually proven to be worth the cost.

1. Model name: TR-20

2. Model availability:

   a. Available for general usage? Yes - order through NTIS; cost $150.00

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?

3. Computer requirements:

   a. What programming language was used?

      Fortran II

   b. Computer system used for model development?

      IBM 7090/7094

   c. Is program readily adaptable to major computer systems other than the one indicated above?

      Yes

4. Data base requirements:

   a. Is model continuous or event? Event

   b. Briefly describe data input requirements.

      <u>Runoff</u>
      Subbasin area, curve number, time of concentration, rainfall events, antecedent moisture conditions

      <u>Routing</u>
      Stage-discharge - Cross section area relationship for stream cross sections
      Stage-storage - discharge relationship for reservoir routing

5. Model applications:

   a. Was model developed for a particular study area and, if so, which area?

      No

b. Are calibration results available for any past applications?

Yes

c. Does the model have the demonstrated capability of reproducing historic flow events?

Very limited

d. Can the model be used to simulate flows that might occur under future land use conditions?

Yes

6. Basic model theory and methodologies:

a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

Runoff based on curve number concept which gives inches of runoff for inches of rainfall. Curve number based on empirical data relating soil type and land use to observed runoff. Three antecedent moisture conditions may be chosen to describe dry, normal or wet soil.

Routing based on modified Muskingham method using triangular unit hydrographs. Reservoir routing is modified Puls routing.

b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

Yes, implicitly, assign a high curve number to simulate high runoff and use reservoir routing as per guidelines in SCS Minnesota Hydrology Handbook to account for storage of marshes.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

No

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

Yes

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

   No

10. Can the model route flows in both open channels and pipes or neither?

   Open channel only

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

   Yes

12. Briefly discuss any unique features of the model that are not covered in any of the above questions.

   Model accepted by SCS, easy to use, hard to verify results, not really intended for Red River of the North type of analysis.

13. Provide any data you can readily obtain on costs for running this model.

   Very cheap

   6 storms, 20 subbasins, 15 reaches, 4 structures, $25.00

1. Model name: USDAHL

2. Model availability:

   a. Available for general usage? Yes

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?

      Contact Dr. Engman at (304) 344-3490 USDA Hydrographic Laboratory; Beltsville, Maryland

3. Computer requirements:

   a. What programming language was used?

      Level E Fortran IV

   b. Computer system used for model development?

      IBM 360-30

   c. Is program readily adaptable to major computer systems other than the one indicated above?

      Yes

4. Data base requirements:

   a. Is model continuous or event?

      Continuous

   b. Briefly describe data input requirements.

      Continuous rainfall (average over basin), water equivalent of snowfall, infiltration rate, surface storage, watershed characteristics

5. Model applications:

   a. Was model developed for a particular study area and if so which area?

      No

   b. Are calibration results <u>available</u> for any past applications?

      Yes, sample decks available

c. Does the model have the demonstrated capability of reproducing historic flow events?

   No. Best at daily, long-term runoff. Cannot reproduce peaks for time periods shorter than daily.

d. Can the model be used to simulate flows that might occur under future land use conditions?

   Yes, simulates long-term water yield well. It was designed for this.

6. Basic model theory and methodologies:

   a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

      Runoff based upon Horton's infiltration equation. Rainfall in excess of infiltration is routed across actual soil zones to the channel based upon an empirical relationship by Musgrave and Holton.

   b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

      Yes, implicitly, user specifies inches of surface storage and infiltration rate.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

   Snowmelt is tabulated as water equivalent; does not simulate accumulation and melt directly.

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

   No, limited routing

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

   No

10. Can the model route flows in both open channels and pipes or neither?

Uses a storage function for channel routing.

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

No

12. Briefly discuss any <u>unique</u> features of the model that are not covered in any of the above questions.

Describes in detail the vertical variations in soil characteristics using layers.

13. Provide any data you can readily obtain on costs for running this model.

Less than $10/water year

1. Model name: STORM

2. Model availability:

   a. Available for general usage? Yes

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?

3. Computer requirements:

   a. What programming language was used?

      Fortran IV

   b. Computer system used for model development?

      CDC/Univac/IBM

   c. Is program readily adaptable to major compu r systems other than the one indicated above?

      Yes

4. Data base requirements:

   a. Is model continuous or event? Continuous

   b. Briefly describe data input requirements.

      Rainfall record converted to STORM format. Two means of runoff calculation:

      Coefficient method: uses runoff coefficient, pervious and impervious area for each subbasin, depression storage, pan evaporation rates, subbasin area

      SCS curve number method: uses land use, pan evaporation and soil moisture parameters

5. Model applications:

   a. Was model developed for a particular study area and if so which area?

      No

b. Are calibration results _available_ for any past applications?

Yes

c. Does the model have the demonstrated capability of reproducing historic flow events?

In a limited sense--overland flow only, no routing capabilities

d. Can the model be used to simulate flows that might occur under future land use conditions?

Yes

6. Basic model theory and methodologies:

a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

Runoff coefficient method - assumes a given fraction of rainfall will runoff each hour of each rainfall event once a user-specified depression storage has been filled.

SCS method - SCS curve number rainfall-runoff relationship with simplified soil moisture accounting to establish antecedent moisture conditions which then determine the curve number and establish the overland flow runoff.

Routing overland flow routing can be used with either method based on SCS triangular unit hydrograph.

b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

Yes, implicitly - using coefficient method specify a highly impervious area with a large depression storage

- using SCS method specify large initial abstraction with small soil moisture storage characteristics.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

   Yes, uses degree day method, requires daily air temperature record; if temperature below freezing, precipitation is snow and is added to snowpack. If the temperature 32°F, melt occurs as controlled by melt coefficient.

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

   No

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

   No

10. Can the model route flows in both open channels and pipes or neither?

    No

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

    Yes

12. Briefly discuss any <u>unique</u> features of the model that are not covered in any of the above questions.

    Calculates nonpoint source pollutants

13. Provide any data you can readily obtain on costs for running this model.

    Inexpensive to run, hourly time steps, more than TR-20 less than HSPF.

1. Model name: ILLUDAS

2. Model availability:

   a. Available for general usage?

      Yes, can obtain program deck (Fortran IV) at cost from the Illinois State Water Survey, or arrange to use on Boeing Computer Services, Inc. system.

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?

      No proprietary rights.

3. Computer requirements:

   a. What programming language was used?

      Fortran IV

   b. Computer system used for model development?

      N/A

   c. Is program readily adaptable to major computer systems other than the one indicated above?

      Yes, little storage required and Fortran IV is a widely used programming language.

4. Data base requirements:

   a. Is model continuous or event? STORM event

   b. Briefly describe data input requirements.

      Run Information: use in evaluation mode or design mode.

   Basin Parameter Inputs:
      Total drainage area, precipitation abstractions, paved and grassed areas, hydrologic soil group (A, B, C, or D)

   Rainfall Parameter Inputs:
      Either directly input hyetograph or program will distribute total precipitation.
      User Input: Number of time increments, time step, antecedent moisture condition (1,2,3, or 4), incremental rainfall.

Program Distribution: Time step, duration, total rainfall, antecedent moisture condition (1,2,3, or 4).

Channel or Pipe Branch Parameter Inputs:
Network description - branch, reach, storage element type section (circular, rectangular, trapezoidal) Length, slope, Manning's 'n', diameter, height, width, lateral slope of branch. Available storage of detention storage element.

Sub-Basin Parameter Inputs:
Directly connected paved area, supplemental paved area, and grass area for each branch with hydrologic soil group (A,B,C, or D).
Either time of concentration or length of flow path and slope of each element.

5. Model applications:

a. Was model developed for a particular study area and if so which area?

The model was developed and tested using recorded streamflow data from 21 urban and 2 rural watersheds from across the United States. Preliminary work was based on soil data of Illinois soil groups and tested for applicability to soils of other areas. Rainfall distribution in program is also of Illinois origin.

b. Are calibration results available for any past applications?

Yes, the model development, calibration and verification is well documented in The Illinois Urban Drainage Area Simulator, ILLUDAS , Bulletin 58, Illinois State Water Survey, 1974. It was tested on 23 different basins across the U.S. for several storms each and results are tabularized comparing computed versus observed runoff volumes and peak flows.

c. Does the model have the demonstrated capability of reproducing historic flow events?

Yes, results are acceptable in the majority of basins with little or no adjustment of original parameters. Most applications are completely deterministic.

d. Can the model be used to simulate flows that might occur under future land use conditions?

   Yes, it is easily adaptable to such changes in impervious (paved) surface.

6. Basic model theory and methodologies:

   a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

Equal time increments of rainfall are applied to three drainage elements tributary to a reach within a system network. Directly connected paved area, indirectly connected paved area, and grassed area runoff are calculated and routed overland using a time-area routing procedure. Overland travel time may be directly input or program-calculated. Initial rainfall abstractions are subtracted at the beginning of an event and paved area runoff occurs from all excess. Directly connected area is routed separately, indirectly connected is added onto the grassed area and routed with excess rainfall of this element. Horton's equation is used to determine infiltration in grassed areas. Specification of hydrologic soil group A,B,C, or D assigns predetermined soil characteristics as input to infiltration curves. Antecedent moisture condition 1, 2, 3, or 4 specifies starting points on the curves and is directly related to the amount of precipitation occurring in the previous 5-day period.

The channel network may consist of circular, rectangular, or trapezoidal sections. Flows can be routed by either a time shift or lag method without storage considerations, or an implicit solution of the continuity equation using Manning's equation to define a stage-discharge curve for each cross section. Indirect computation of flow volume in excess of system gravity flow capacity allows analysis of detention storage volume requirements.

   b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

   At best, the model could only cursorily address the effects of wetland storage by use of the detention storage volume element for offstream storage. Operation rules of this detention storage element are inflexible, though, and render the capability marginally useful.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

   There are no snowmelt considerations within the model. Melt would necessarily require quantification and input within the rainfall distribution.

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

   Yes, the model is able to simulate natural open channel hydraulics of a branching drainage network (no parallel channels) with idealized trapezoidal channel cross sections (no floodplain is delineated). Large impoundment operations cannot be directly simulated.

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

   Yes, the model addresses subsurface drainage facilities of a branching drainage network of either circular or rectangular closed conduits. Surcharge or pressure flow is not addressed; flow in excess of gravity flow capacity is accumulated by the model as detention storage.

10. Can the model route flows in both open channels and pipes or neither?

    A network can incorporate any mix of the three types of drainage structure.

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

    No, only one hyetograph can be specified for the entire watershed.

12. Briefly discuss any <u>unique</u> features of the model that are not covered in any of the above questions.

    ILLUDAS primary utility is in the evaluation and/or design of storm drainage facilities in an urban or urbanizing watershed. It is an easy and inexpensive tool to use and the required inputs are readily available from standard sources. The model was not developed for utilization in large watersheds, testing was performed on basins less than 10 square miles in area. It was designed to be a deterministic tool and is not geared towards calibration of soil parameters. Channel routing is valid only for gravity flow conditions in the closed conduits.

13. Provide any data you can readily obtain on costs for running this model.

Costs vary with the computer system used and size of network being analyzed. Slightly more expensive than most event type models.

1. Model name: MITCAT

2. Model availability:

   a. Available for general usage? Yes, propietary.

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?

      Rights held by: Resource Analysis
      235 Wyman Street
      Waltham, Massachusetts 02154
      (617) 890-1201

      Charges a "User's Fee" for those using MITCAT on the MCAUTO time sharing system.

3. Computer requirements:

   a. What programming language was used?

      Fortran IV (extended)

   b. Computer system used for model development?

      M.I.T. system

   c. Is program readily adaptable to major computer systems other than the one indicated above?

      Yes - MCAUTO
      ITEK/IBM
      CDC at Lawrence Barkley Lab

4. Data base requirements:

   a. Is model continuous or event?

      Either - has independent hydrologic formulations, one for event, one for continuous. Continuous formulation not as well tested.

   b. Briefly describe data input requirements.

      1. User oriented, free format input.
      2. Parameters physically based, minimizes need for calibration.
      3. Needs precipitation (daily for continuous, hourly for event), land cover, infiltration rates from SCS maps, and stream channel characteristics

5. Model applications:

   a. Was model developed for a particular study area and if so which area?

      Developed as a "general" model, most applicable to urban or transitional basins.

   b. Are calibration results available for any past applications?

      Yes, at least for the event model.

   c. Does the model have the demonstrated capability of reproducing historic flow events?

      Yes, for events. However, it is advertised as not requiring calibration, hence significant reproduction of historic events may not be available.

   d. Can the model be used to simulate flows that might occur under future land use conditions?

      Yes, developed for study of urban areas and rural areas that are urbanizing.

6. Basic model theory and methodologies:

   a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

      Routing Event model - overland, kinematic wave and channel, kinematic wave
      Continuous model - overland not routed, channel uses modified Puls

      Infiltration
      Event model, Holton, Horton, SCS or runoff coefficient; continuous model, "simplified."

   b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

      Yes, can use depression storage algorithms to model implicitly.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

   No

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

   Yes, very well adapted to drainage network analysis.

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

   Maybe through modification of the interflow parameters.

10. Can the model route flows in both open channels and pipes or neither?

    Both, as long as flow is unidirectional.

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

    Yes

12. Briefly discuss any <u>unique</u> features of the model that are not covered in any of the above questions.

    Very user oriented

13. Provide any data you can readily obtain on costs for running this model.

    No hard data available. Corps of Engineers evaluates it as very inexpensive, but they looked only at the event option.

1. Model name: HEC-1

2. Model availability:

   a. Available for general usage? Yes, from HEC at a cost of about $120.00.

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?

      None

3. Computer requirements:

   a. What programming language was used?

      Fortran IV

   b. Computer system used for model development?

      Univac 1108 and CDC 6600, 7600

   c. Is program readily adaptable to major computer systems other than the one indicated above?

      Yes

4. Data base requirements:

   a. Is model continuous or event? Event

   b. Briefly describe data input requirements.

      A. Precipitation Data
         1. Known precipitation by area
         2. Synthesized from nonrecording areas relative to annual rainfall and station weights
         3. Standard project storm prediction methods

      B. Snowfall/Snowmelt Data
         1. Temperature/elevation data, lapse rates, snowmelt by rain coefficients, etc.
         2. Meteorological data

      C. Loss Rate Data
         1. Initial, incremental coefficients for rainfall and snowmelt

      D. Unit Hydrograph Data
         1. If not supplied, will be computed by Clark method

E. Base Flow/Routing Data
   1. Exponential expression flow at beginning and end of interval. This developed base flow is added to computed runoff.
   2. Uses Modified Puls, Muskingum, working R&D, Storage-Routing to develop hydraulics in stream system. Combines flows.
   3. Needs the usual time step size, storage data, inflow/outflow data from reach; discharge curves, etc. for whatever method is selected.

5. Model applications:

   a. Was model developed for a particular study area and if so which area?

      Not for any particular area

   b. Are calibration results available for any past applications?

      Test data and calibration data are probably available from HEC but not necessarily for the type of problem described in the Red River of the North Basin.

   c. Does the model have the demonstrated capability of reproducing historic flow events?

      In most single storm calibrations on the West Coast, it has done well.

   d. Can the model be used to simulate flows that might occur under future land use conditions?

      Not particularly easy to do, since land use is not an input. Drainage area, loss rate coefficient, and hydrograph information must incorporate runoff changes due to land use.

6. Basic model theory and methodologies:

   a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

Runoff - Loss rates in form of initial abstraction, uniform or dependent on rainfall/snowmelt intensity and soil moisture are applied to the precipitation pattern over a time history to compute excess runoff.

Routing - No independent overland flow capability exists except as incorporated in defining a particular base flow function. The channel routing is all done by one of several coefficient methods. Implicit dynamic routing is not available.

b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

   This model was not specifically developed for this problem.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

   Yes, the program does have hydrometeorological relationships to represent snow accumulation, loss rates and snowmelt in each elevation zone. The expressions are generally based on the energy - budget methods. Snowmelt is cumulative and either adds or subtracts from snowpack.

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

   In the form of a tributary to the main stem but not as off channel or overbank storage. To be used as a tributary, an inflow hydrograph would need to be developed.

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

   No

10. Can the model route flows in both open channels and pipes or neither?

    Open channel routing - no pressure flow capability.

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

    Only by subarea. Each subarea would have to be evaluated separately for the precipitation/runoff process.

12. Briefly discuss any unique features of the model that are not covered in any of the above questions.

   a. Contains optimization techniques for hydrologic coefficients of a routing method. Helps develop best fit between observed and computed hydrographs.

   b. Computes economic damage analysis for multiple floods and compares flood probabilities/annual damages. Includes graphical displays of results.

13. Provide any data you can readily obtain on costs for running this model.

   Costs will, of course, vary with the size and type of analysis being performed. However, the general cost range on our DEC-10 is about $10-50 for most applications. For a very large basin (i.e., Red River of the North), the watersheds will probably have to be broken into subbasins at about the same above cost per subbasin per run.

1. Model name: HYMO

2. Model availability:

   a. Available for general usage? Yes

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?

      N/A

3. Computer requirements:

   a. What programming language was used?

      Fortran IV

   b. Computer system used for model development?

      IBM 36065

   c. Is program readily adaptable to major computer systems other than the one indicated above?

      Yes, it is currently running on a DEC-10. Requires 73 K storage.

4. Data base requirements:

   a. Is model continuous or event? Event

   b. Briefly describe data input requirements.

      1. Mass rainfall curve(s) data.
      2. SCS curve number (CN value) for each sub-watershed.
      3. Instantaneous unit hydrograph (IUH) parameters.
      4. Channel routing data including valley sections or rating curves and reach lengths and slopes.
      5. Reservoir routing data including outflow/storage table.

5. Model applications:

   a. Was model developed for a particular study area and if so which area?

      No. However, regression equations are built in which compute IUH parameters (K&Tp) based on watershed length and slope. These equations were derived from watersheds located in the southern U.S. Their use however, is optional.

b. Are calibration results available for any past applications?

Yes. An example for Brushy Creek watershed near Riesel, Texas is given in the HYMO Users Manual.

c. Does the model have the demonstrated capability of reproducing historic flow events?

Not really proven

d. Can the model be used to simulate flows that might occur under future land use conditions?

Yes

6. Basic model theory and methodologies:

a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

1. Runoff is computed by application of the SCS rainfall/runoff equation.
2. Overland flow is computed by application of an IUH. The rising limb, to the inflection point, is represented by a two-parameter gamma distribution and the recession limb is represented by an exponential decay curve.
3. Channel routing is computed by the "Variable Storage Coefficient" (VSC) method. This method is a hydrologic rather than a hydraulic routing technique. However, variations in the reach storage time constant during the flood are accounted for which results in greater accuracy than other hydrologic routing methods.

b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

Implicitly, these factors can be accounted for by selection of the proper IUH parameters. If observed hydrographs exist these parameters can be obtained from analysis of the recorded events.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

No

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

   Yes. These effects can be accounted for by either modification of IUH parameters or by channel routing through the drainage ditches.

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

   No

10. Can the model route flows in both open channels and pipes or neither?

    Open channel routing can be handled in a straightforward manner. However, pipe routing can be handled by reading in rating curves.

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

    Yes. A different mass rainfall curve could be used for each subarea if the user desires.

12. Briefly discuss any <u>unique</u> features of the model that are not covered in any of the above questions.

    The model is easy to use. Free format input and well designed output formats result in few coding and interpretation errors. Printer plots are available for comparing inflow and outflow hydrographs as well as observed and computed hydrographs. An error analysis routine is available for analysis of observed versus computed hydrographs.

13. Provide any data you can readily obtain on costs for running this model.

    The cost of running this model is very low. It requires only 73k storage and utilizes simple, rather than sophisticated, mathematical algorithms. Exact costs will vary with each computer installation and are unknown.

1. Model name: SSARR

2. Model availability:

   a. Available for general usage? Available to other Corps Districts by direct access or tape/card deck.

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?

      None - program is running on CH2M HILL DEC-10 system.

3. Computer requirements:

   a. What programming language was used?

      Fortran IV

   b. Computer system used for model development?

      IBM

   c. Is program readily adaptable to major computer systems other than the one indicated above?

      Yes, has been adapted to GE, Honeywell and CDC.

4. Data base requirements:

   a. Is model continuous or event? Continuous

   b. Briefly describe data input requirements.

      Temperature data, precipitation data, soil moisture data, basin geometry, stream system data, reservoir elevation, surface area/volume data

5. Model applications:

   a. Was model developed for a particular study area and if so which area?

      Basically for Columbia River basin, but is generally applicable to most any basin.

b. Are calibration results available for any past applications?

Has been used in many states of the U.S. and by several foreign countries. It is presently being used by 3 provinces in Canada, which probably have problems similar to the Red River of the North. These kinds of studies and results are available through the appropriate channels.

c. Does the model have the demonstrated capability of reproducing historic flow events?

Apparently so. The model seems to be widely accepted and used.

d. Can the model be used to simulate flows that might occur under future land use conditions?

Yes, but not directly. Changes would have to be made to such things as soil moisture data and runoff data.

6. Basic model theory and methodologies:

a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

The model uses a thermal index type of accumulation/melt procedure for snow. It includes a continuous form of soil moisture accounting. The storage routing procedures are nonlinear and can include impacts of different inflow and outflow relations. Diversions, return flows, baseflow and overbank considerations are available either directly or indirectly through manipulation of the options.

The channel routing is the coefficient method of Modified Puls and can account for backwater in tributary streams due to high water in the mainstem.

The program can be run for river routing, precipitation/runoff or reservoir operations separately or combined.

b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

The model is supposed to be able to handle wetlands operations through use of the storage routing reservoir operations sections and diversions/return flow sections. This would be an implicit operation accomplished by making the code do something it doesn't know it is doing.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

   Snowpack/melt is most likely calculated in an implicit manner based on temperature/precipitation data.

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

   Implicitly, through the use of diversion/return flow options.

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

   No

10. Can the model route flows in both open channels and pipes or neither?

    Open channel or free pipe flow through stage-discharge relations but no pressure flow.

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

    Yes, it has the ability to handle variable precipitation data over an area.

12. Briefly discuss any unique features of the model that are not covered in any of the above questions.

    This is a continuous solution program with several options for a unique problem. There are graphical display capabilities included.

13. Provide any data you can readily obtain on costs for running this model.

    The best data on costs show about a $10-50 range similar to other codes. The time step and number of options has a direct impact on costs. This cost was for a 300-400 square mile area with 3 precipitation stations

but no routing. The routing is quite cheap, however. The system was a CDC 7600 and IBM 371-55 with costs of $10 and $12 respectively to generate the runoff from precipitation and snowmelt.

1. Model name: MMDW

2. Model availability:

   a. Available for general usage? Yes

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?

      Not proprietary contact: Curtis L. Larson
      Department of Agricultural Engineering
      University of Minnesota

3. Computer requirements:

   a. What programming language was used?

      Fortran IV

   b. Computer system used for model development?

      CYBER 74 - Control Data Corporation

   c. Is program readily adaptable to major computer systems other than the one indicated above?

      Probably

4. Data base requirements:

   a. Is model continuous or event? Continuous

   b. Briefly describe data input requirements.

      1. Soil data - conductivities, matric suctions and average suction at wetting front as functions of relative moisture content.
      2. Watershed parameters for each element.
      3. Snow accumulation and snowmelt parameters.
      4. Channel routing parameters.
      5. Hourly precipitation, monthly evaporation, and daily temperature.
      6. Clear day solar radiation and wind speed.

5. Model applications:

   a. Was model developed for a particular study area and if so which area?

The model is somewhat general in concept, but was developed for watersheds with considerable depressional storage and surface and subsurface drainage.

b. Are calibration results available for any past applications?

Yes, for Jackson County Ditch II and Little Sioux River in southwestern Minnesota. Has not been widely applied.

c. Does the model have the demonstrated capability of reproducing historic flow events?

Yes, based on limited applications.

d. Can the model be used to simulate flows that might occur under future land use conditions?

Yes

6. Basic model theory and methodologies:

a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

Rainfall and snowmelt are subjected to a complex infiltration algorithm based upon the Green-Ampt and Mein-Larson equations. Water available for runoff appears instantaneously as depression inflow and is subjected to the algorithms in the drainage phase. There is no overland flow routing of runoff. This would tend to limit its application to smaller elements where overland flow routing is not significant.

Stream channel routing is semidynamic using a kinematic wave formulation. Not simplified to the extent in other models and requires an iteration solution using the Newton and bisection techniques. Has good snowpack and snowmelt algorithms based upon conservation of energy. Uses the same basic procedures as in HSPF with a slight modification in the manner in which the MMDW computes the net terrestrial radiation.

b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

Yes, designed conceptually to do so.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

   Yes

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

   Yes

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

   Yes, designed conceptually to do so.

10. Can the model route flows in both open channels and pipes or neither?

    Open channel and drain tiles.

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

    Not readily determinable.

12. Briefly discuss any unique features of the model that are not covered in any of the above questions.

    The major features of the model are the surface and subsurface drainage procedures and the procedure for determining infiltration.

13. Provide any data you can readily obtain on costs for running this model.

    No cost information is available, but estimates of run time from 70 to 90 seconds per month for a relatively small watershed are given. Based upon commercial computer rates, it would be very expensive to run in a continuous mode.

1. Model name: RROUT

2. Model availability:

   a. Available for general usage? Yes

   b. If proprietary rights exist who holds them and what arrangements would be required to access the program?
      No proprietary rights claimed.

3. Computer requirements:

   a. What programming language was used?

      Fortran IV

   b. Computer system used for model development?

      Operational on a DEC-10 system.

   c. Is program readily adaptable to major computer systems other than the one indicated above?

      Yes

4. Data base requirements:

   a. Is model continuous or event?

      Land phase is continuous, channel routing is event.

   b. Briefly describe data input requirements.

      Hourly precipitation.

      Evapotranspiration potential, solar radiation, max/min daily temperature, windspeed.

      Land use parameters and hydrologic soil grouping.

      Stream channel parameters to define the drainage network.

5. Model applications:

   a. Was model developed for a particular study area and if so which area?

      No

b. Are calibration results available for any past applications?

Yes

c. Does the model have the demonstrated capability of reproducing historic flow events?

Yes

d. Can the model be used to simulate flows that might occur under future land use conditions?

Yes

6. Basic model theory and methodologies:

a. Very briefly describe the theory and methodology used to compute excess rainfall (runoff) and flow routing (overland and channel).

The model uses the Stanford Watershed Model with expanded snowmelt capabilities to compute land surface runoff files (same basically as HSPF and the DLBM). Major runoff events are extracted from the runoff files and subjected to the routing algorithm which is a version of the kinematic wave equations simplified so that an explicit solution can be obtained. A single event can be analyzed or an annual maximum peak series can obtained and a frequency analysis performed. A log Pearson Type III and a Gumbel frequency analysis can be performed by a user specified option. The results are the 2-, 5-, 10-, 25-, 50- and 100-year peak discharges at locations specified by the user.

b. Can the model simulate wetland (marshes, swamps, bogs) storage effects either explicitly or implicitly? If yes to either, briefly discuss.

Implicitly, by the use of the upper zone storage function.

7. Can the model simulate snowpack accumulation and snowmelt either explicitly or implicitly? If yes to either, briefly discuss.

Yes, the model has incorporated the work on snowmelt done by Dr. Eric Anderson, now of the National Weather Service, for his doctoral at Stanford University.

8. Can the model simulate the effects of major surface drainage projects, i.e., large drainage ditches?

   Yes

9. Can the model simulate the effects of major subsurface drainage projects either explicitly or implicitly? If yes to either, briefly discuss.

   Implicitly, through the use of interflow components of the Stanford Watershed Model. It would require data for calibration and would be an approximation at best.

10. Can the model route flows in both open channels and pipes or neither?

   Open channel and pipes that are not surcharged.

11. Can the model simulate the spatial variability in precipitation required for application to the larger watersheds?

   Yes

12. Briefly discuss any unique features of the model that are not covered in any of the above questions.

   The land surface runoff files only need to be generated one time and they provide the basis for looking at a wide range of alternatives in a cost-effective manner.

13. Provide any data you can readily obtain on costs for running this model.

   The runoff files will cost around $4.00/year for each soil or segment type. The routing costs are reasonable. A 30-year run on a watershed with 40 segments and 40 channel reaches with a frequency analysis at 30 location with cost around $100.00.

APPENDIX D
AVAILABLE DATA

Several types of data will be required for the operation of a hydrologic/hydraulic model in the Rush River and Marsh Creek watersheds. These data and sources may also be applicable to other areas throughout the Red River of the North basin.

	Data	Description and Source
1.	Streamflow Records	Surface Water Records of North Dakota, U.S. Geological Survey. One station in Rush River watershed and five stations in or near Cass County, North Dakota
		Surface Water Records of Minnesota, U.S. Geological Survey. Four stations near Marsh Creek in Norman County, Minnesota
		Water Resources of the Wild Rice River Watershed, Northwestern Minnesota, T. C. Winter, L. E. Bidwell, R. W. Maclay, HA-339, 1970
		Water Resources of the Red River of the North drainage basin in Minnesota, USGS Water Resources Investigation I-72. T. C. Winter, L. E. Bidwell, R. W. Maclay, 1972
		Red River of the North Regional Flood Analysis, Minnesota Department of Natural Resources and North Dakota State Water Commission, 1971

2.	Meteorological Data	National Weather Service Office, Fargo, North Dakota (hourly precipitation, temperature, wind speed and direction, sunshine duration)
		National Weather Service Data Station, Amenia, North Dakota (temperature and precipitation)
		National Weather Service Data Station, Bemidji, Minnesota (temperature and precipitation)
		National Weather Service Data Station, Twin Valley 3 SW, Minnesota (precipitation)
		National Weather Service Data Station, Mahnomen 1 W, Minnesota (temperature and precipitation)
		National Climatic Center, Ashville, North Carolina
3.	Snow	National Weather Service, St. Paul, Minnesota, and Corps of Engineers, St. Paul District. Cooperative snow depth and water content survey
4.	Soils Characteristics	U.S. Soil Conservation Service Soil Survey. Norman County, Minnesota
		U.S. Soil Conservation Service Soil Survey Data (unpublished until 1981-82), Cass County, North Dakota
		U.S. Soil Conservation Service Soil Survey, Traill County and Richland County, North Dakota

		Soils Survey (reconnaissance) of the Red River of the North Valley Area, Minnesota, C. C. Nikiforoff, Bureau of Chemistry and Soils and E. A. Fieger, University of Minnesota, April 1939
		U.S. Soil Conservation Service General Soils Map, Mahnomen County, Minnesota
		North Dakota Geological Survey, Grand Forks, North Dakota
5.	Drainage Characteristics	U.S. Geological Survey Topographical Maps, surface only
		U.S. Soil Conservation Service, Fargo, North Dakota, subsurface
		U.S. Soil Conservation Service, Area 1 (north), Area 2 (south), Minnesota
		Agricultural Engineering Department, University of Minnesota, Dr. Curtis L. Larson
		North Dakota Geological Survey, Grand Forks, North Dakota
6.	Vegetation - Rush River	LANDSAT Satellite Imagery, EROS Data Center, Sioux Falls, South Dakota
		U-2 Photos, EROS Data Center, Sioux Falls, South Dakota
		Corps of Engineers, Sheyenne Basin Report, St. Paul, Minnesota

		U.S. Forest Service, Statewide Woodland Inventory, (to be completed in 1980)
		Souris-Red-Rainy Basin Study
		North Dakota State University, Dr. Harold Goetz--Biology Department, Dr. Frank Cassel--Biology Department
7.	Vegetation - Marsh Creek	LANDSAT Satellite Imagery, EROS Data Center, Sioux Falls, South Dakota
		U-2 photos, EROS Data Center, Sioux Falls, South Dakota
		Original Vegetation of Minnesota, 1930's, reprinted 1974, University of Minnesota
		State Forestry Map, Minnesota State Planning Agency
		Souris-Red-Rainy Basin Study
8.	Geology - Rush River	Geology and Ground-Water Resources of Cass County, North Dakota, Bulletin 47 Part I (NDGS)
		Report of Investigations No. 54, Physical Data for Land Use Planning in Cass County, North Dakota and Clay County, Minnesota (NDGS)

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		ASCS Aerial Photos, Norman County--1939, 1948, 1954, 1966, (University of Minnesota)
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Classification Manual for Land Use and Land Cover for the State of Minnesota (MSPA)

Land ownership map, State of Minnesota (Minnesota State Planning Agency)

APPENDIX E
MODEL SYNOPSIS

(See Chapter 3 section, entitled "Detailed Model Descriptions" for more thorough discussion of model algorithms.)

SWM - Stanford Watershed Model (SWM)

Forerunner of most continuous, deterministic simulation models of the hydrologic process. Calculates land surface effects, including hydrologic budget and overland flow routing. Does not address channel flows.

HSP - HYDROCOMP Simulation Program

Comprehensive hydrologic, hydraulic, water quality and data management program package applied extensively during the past decade. Written in PL1 language and is a proprietary package copyrighted by HYDROCOMP, Inc. Composed of five major modules:

LIBRARY - data management package

LANDS - hydrology package, based upon and nearly identical to SWM

CHANNEL - hydraulic routing package, using storage routing for low flows and dynamic, kinematic wave routing for higher flows

QUALITY - water quality simulation package

UTILITY - additional data management routines

HSPF - HYDROCOMP Simulation Program, Fortran version

Newest version of HSP. Revised extensively to improve computer utilization and update abilities as well as additional capabilities. Some algorithms different from HSP. Written in standard Fortran (except for use of half-word integer option) for EPA. Available through EPA. Composed of five main modules:

TSPUT - time series data management module

PERLND - module for calculation of runoff, both quantity and quality, from pervious areas. Uses SWM hydrologic algorithms

IMPLND - module for calculation of runoff, both quantity and quality, from impervious areas. Based on SWM algorithms for impervious surface runoff

RCHRES - stream and reservoir hydraulic, advection and quality dynamics module. Hydraulic algorithms differ from previous versions of HSP in requiring user specification of stage discharge relationships which were previously calculated internally for a limited variety of cross sections

UTILITY - additional data management routines

UROS - Urban Flood Simulation Model

Hydraulic routing and flood analysis program developed at the Georgia Institute of Technology. Designed for use in conjunction with the SWM. The SWM is used to calculate long-term, continuous runoff hydrographs. Critical runoff events (annual series, partial duration series, etc.), are input to UROS for channel routing. Routing is kinematic, calculations similar to those of the original HSP CHANNELS. An improved version of UROS is also available as a proprietary model. (See Lumb and Douglas, October 1976, "Runoff Files for Flood Hydrograph Simulation," ASCE Journal of the Hydraulics Division, HY10.)

RROUT - Runoff and Routing Model

Hydraulic routing and flood analysis program developed from UROS. Has additional output and diversion capacity somewhat similar to the improvements included in the proprietary version of UROS. CH2M HILL, INC., implemented the modifications, but claims no proprietary rights in RROUT.

MMDW - Minnesota Model for Depressional Watersheds

Hydrologic and hydraulic deterministic model of continuous water balance and runoff routing. Constitutes a significant modification of SWM which is particularly adapted for explicit representation of depression storage and tile drainage. Developed at the University of Minnesota. Composed of four modules:

SNOW - calculates snowmelt and accumulation

LAND - calculates land surface effects, including hydrologic budget and excluding overland flow routing

DRAINAGE - calculates the effects of depression storage and tile drainage, using continuity, empirical depth-storage and depth-discharge, and seepage concepts for routing

CHANNEL - hydraulic routing package, uses kinematic wave assumptions differing from HSP, UROS and RROUT primarily in the nature of the discharge area equation.

APPENDIX F
REFERENCES

1. Dr. Norman Crawford - HYDROCOMP, Inc., Palo Alto, California

2. Dr. Bharat M. Parekh-North Dakota State University

3. Mr. Marv Alvershire-North Dakota Central Data Processing Center

4. Dr. Danny Fread-National Weather Service, Hydrologic Research Center

5. Mr. Pat Neuman-National Weather Service, St. Paul, RFC

6. Mr. Lee Larson--National Weather Service, Kansas City, RFC

7. Mr. Dean Bratz-National Weather Service, St. Paul, RFC

8. Mr. Norman Prochnow-Soil Conservation Service, North Dakota

9. Mr. Don Barrow-Soil Conservation Service, Minnesota

10. Mr. Harold Jellberg-Soil Conservation Service, North Dakota

11. Dr. Curtis Larson-University of Minnesota

12. Dr. Ian Moore-University of Kentucky

13. Mr. Earl Kuehnast-State of Minnesota

14. Mr. John Blumely-North Dakota Geological Survey

15. Mr. Bill Fifer-U.S. Fish and Wildlife Service

16. Mr. Punch Podoll-Soil Conservation Service

APPENDIX G
NATIONAL CLIMATIC CENTER

The meteorologic data required for hydrologic simulation are available in four separate publications of the National Climatic Center:

1. Hourly Precipitation Data, published monthly for each state. Contains the available hourly precipitation records for all stations within the specified state.

2. Climatological Data, published monthly for each state. Contains daily temperature and precipitation data as well as available soil temperature and evaporation data for all stations in the specified state.

3. Local Climatological Data, published monthly for each first order weather bureau station. Contains all data published for each first order station, including temperature, precipitation, dew point, humidity, and sunshine data. Also describes the station history.

4. Substation History, available for each state. Describes the pre-1955 history of each substation.

Additional nonpublished data may be available from the National Climatic Center or from the individual data stations. Where additional data are required, the National Climatic Center is helpful in locating the available data sources.

Most data available in published form from the National Climatic Center are also available on computer tape. A number of separate tape deck series may have to be accessed in order to obtain all of the desired data types. The Center personnel are trained in aiding users in the definition of which tape series are most appropriate.